Terrestrial Carbon Sequestration in the Northeast: Quantities and Costs

Part 3A. Opportunities for Improving Carbon Storage through Afforestation of Agricultural Lands

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3A. OPPORTUNITIES FOR IMPROVING CARBON STORAGE THROUGH AFFORESTATION OF AGRICULTURAL LANDS

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3A.1 Executive Summary

The main goal of this research is to estimate the maximum potential quantity and associated costs of increasing the storage of carbon by afforestation of existing agricultural land in the 11 states of the Northeast United States. The focus of the work was to quantitatively describe location, the quantity, and at what cost in the region it would be economically attractive to shift agricultural production to afforestation to increase carbon storage. The information contained in this section of the report and subsequent sections of the report can help stakeholders prepare for an uncertain regulatory future by providing more accurate estimates of the quantity of carbon credits that might be available at different price points for various planting or management activities.

Information about current land use (based on state level land cover maps), potential changes in land use and the incremental carbon resulting from the change, opportunity costs, conversion costs, annual maintenance costs, and measurement and monitoring costs were obtained and used in the analyses. The analyses are performed in a geographic information system (GIS), using the county as the scale of resolution, to include the diversity of land uses, rates of carbon sequestration, and costs. As a result, not only are more realistic estimates of the potential supply of carbon produced, but the use of GIS shows where the least to most expensive carbon credits will most likely be found. The general approach was to identify and locate classes of land where there is potential to change the use to a higher carbon content, estimate the cost of changing land use practices, estimate rates of carbon accumulation of afforestation, and then estimate the cost per unit potential CO_2e sequestered at a county scale.

The following steps were used to assess the quantity and cost of potential carbon sequestration through land use change:

- Classify lands found in the region by harmonizing existing state-level land cover maps.
- Identify the major land cover types with potential for carbon sequestration.
- Estimate the area available for each potential land use change.
- Estimate the total costs associated with land use conversion (opportunity, conversion, maintenance, and measuring and monitoring).
- Estimate the quantities of carbon per unit area that could be sequestered for the change in land use over a given time period.
- Combine the estimated sequestered carbon per unit area with corresponding land cover class to estimate the total quantity of carbon at the county scale that could be sequestered using each land use category for a given range of costs in \$/ton CO_2[1].
- Determine the geographic distribution of available carbon at various prices.

Lands were classified into four main groups: cropland, pasture land, forest, and other. The region is dominated by forests (~ 77 million acres), including mixed, deciduous, coniferous, clear cuts, and woody wetlands. Croplands (6.7 million acres) include small grains, row crops, and fallow lands; and pasture (14.7 million acres) includes pasture, hay, & other non recreational grasses. Croplands and pasture lands make up only 6 and 13% of the total land area in the region, respectively (Figure 3A-1). Delaware and Maryland have a high percentage of cropland, with cropland covering 38 and 28% of the land respectively. Pasture land in Pennsylvania and New York are above the regional level at 22 and 19%, respectively. New Jersey does not provide a land cover dataset with pasture as a distinct category. The original New Jersey dataset consists of 55 of land use land cover categories of which pastureland and cropland were a single category. There wasn't a way to separate out pasturelands from croplands. As a result, for New Jersey, cropland was defined as the combination of two other categories, agricultural wetlands, and fallow fields. Pastureland in New Jersey was excluded from the analysis.

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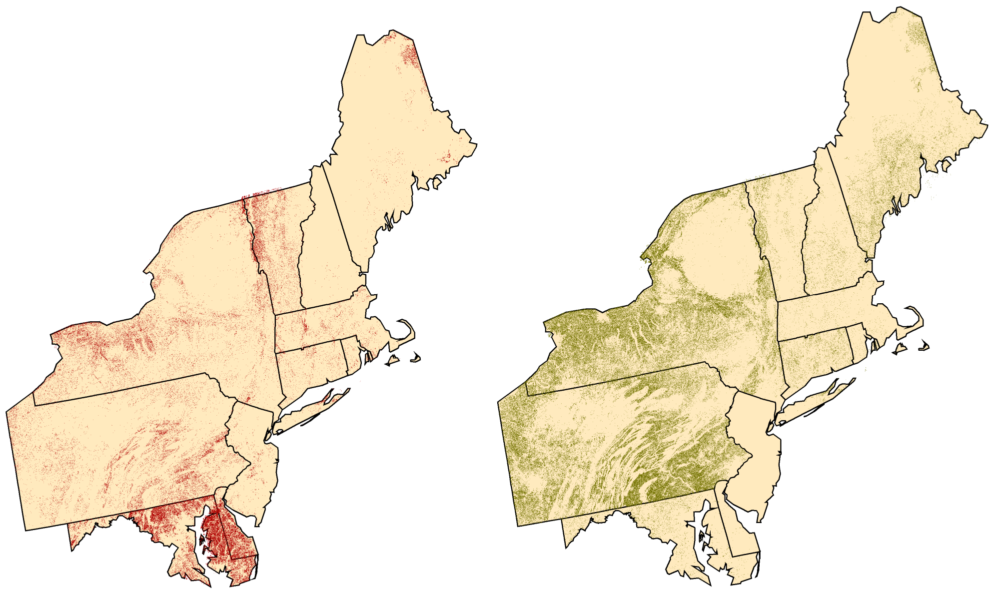
[1]All values given in metric tons. To convert from metric tons to short tons, multiply by 1.102. (If tons in denominator, e.g. \$/ton, divide value by 1.102)

The same situation occurred for Connecticut's 2002 dataset. As a result the 1995 Connecticut land cover data was used which had separate categories for pasture and cropland.



Cropland Pasture Land

Figure 3A-1. Land cover of cropland and pasture in the northeast region

The total cost associated with afforestation of agricultural land has three components: conversion and maintenance costs; monitoring costs, and opportunity cost. The conversion and maintenance costs are those associated with land preparation, planting, and land management. Data on 'conversion cost' was obtained state by state for the region through surveys of entities involved in afforestation activities. Costs differed within each state, with higher costs in Pennsylvania, Connecticut, and Maryland due mainly to measures needed to protect seedlings from deer herbivory. 'Monitoring costs' vary with size of the area being monitored, whether the total area is one large block or disaggregated into smaller parcels, the expected variation in the carbon stocks, the pools being monitored, and the frequency of monitoring. The third component is the 'opportunity costs' associated with loss of income from the current activity. For this section of the analysis, data were collected on the major crops grown in each state, and the respective areas planted over the past 5 years. The dominant agricultural land uses for the region as a whole are corn, hay/pasture, and soybeans. With corn and hay comprising about 3 and 4 million acres respectively; soybeans are a distant third with just over 1.3 million acres harvested annually. Wheat and oats each occupy less than 300,000 acres throughout the region. These data were collected from the USDA National Agricultural Statistics Service (NASS) via their website. In addition, data were compiled on the average (over recent years) prices, production costs, and yields for these dominant crops. Using this information, the average annual profitability per unit area for each crop was calculated. Yields are generally available at the county level and can provide spatial variation on the opportunity costs within each state. The average profitability per crop was weighted by the area that each crop represents within each county/state. This provides a representative opportunity costs for land within each county. Adding the conversion costs, monitoring costs, and opportunity costs together forms the total costs associated with converting agricultural land to forest land.

The costs were variable across the region (Figure 3A-2), but averaged $1600/acre and $2300/acre for a 10 year time period for pasture land and cropland respectively. Costs increase as the length of time increases, with opportunity costs making up a higher proportion of the costs. At 10 years, opportunity costs account for an average of 62% of the total costs, but by 40 years they account for almost 80% of the costs.

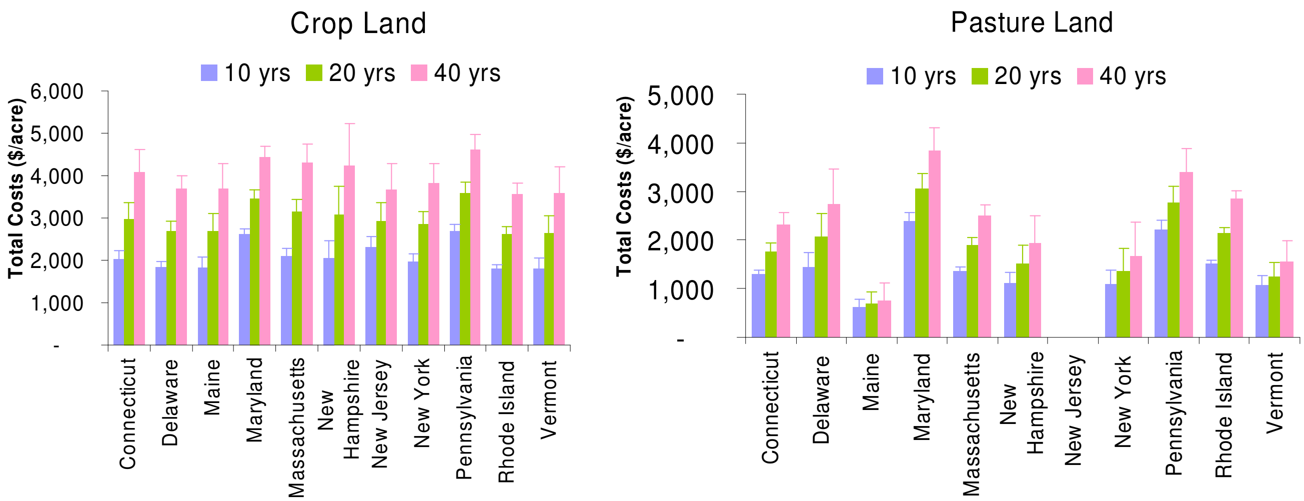


Figure 3A-2. Total costs associated with land use change from agriculture to afforestation.

The carbon sequestration potential of lands in the region was investigated using the USDA Forest Service's FIA (Forest Inventory and Analysis) data sources. The FIA contains the largest database of forest biomass and growth and the database encompasses the entire region. County level data on the carbon stocks of FIA plots were downloaded for all forest types and site productivities. Based on these data, curves of carbon accumulation in biomass were developed for each forest type and site productivity class. These curves of above and belowground biomass were then used to estimate the carbon sequestration potential for each county. The productivity class dominant in the county within the FIA database was assigned to each county. Using an NRI-based database of the land which moved from non-forest in 1987 to a particular forest type in each county in 1997, a forest type was assigned to each county. The appropriate forest type and carbon accumulation curve was then used to estimate the potential carbon sequestered per area of land converted to forest land. Estimated carbon sequestration averaged 31 tons CO_2e/acre after 10 years up to 100 tons CO_2e/acre after 40 years (Table 3A-1, Figure 3A-3). Therefore, an area of 1,600 acres could be expected to accumulate an average of 50,000 tons of CO_2e in 10 years (Table 3A-2). This analysis estimates the change in the live tree biomass only; it does not include fuel emission changes resulting from the change in land management.

Table 3A-1. Range of estimated potential carbon sequestered (in CO_2e) over different time periods per unit area.

	tons of CO_2e/acre		
	10 years	20 years	40 years
weighted mean	31	57	100
Minimum	16	23	49
Maximum	41	74	120

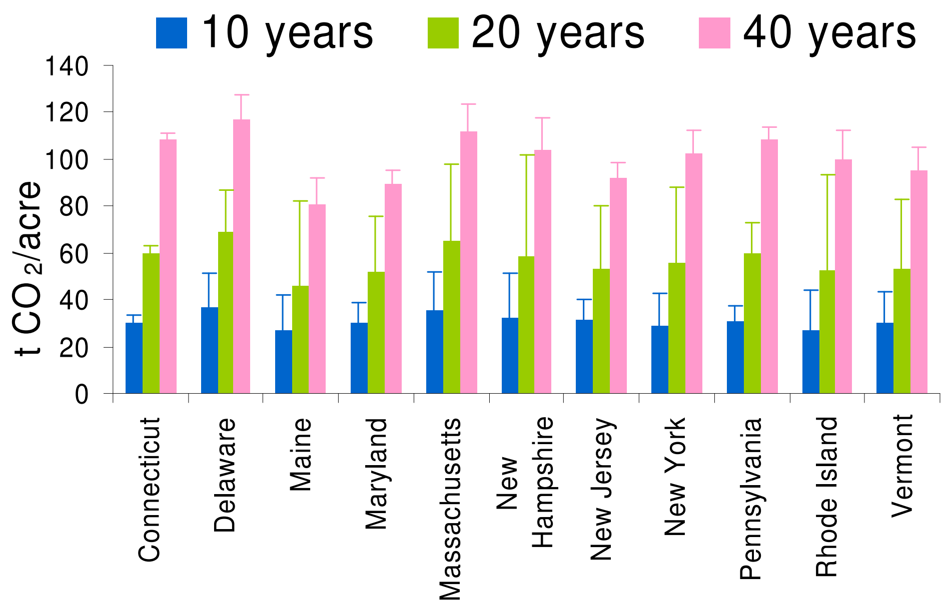


Figure 3A-3. Mean estimated potential carbon sequestered per area in each state (in CO_2e).

Table 3A-2. Estimated afforestation area needed to sequester given amounts of CO_2e.

	Estimated area needed (acres)		
ton CO_2e	10 years	20 years	40 years
10,000 t	327	177	100
50,000 t	1,635	885	498
100,000 t	3,270	1,770	996
1 million t	32,700	17,695	9,962

The final stage in the analysis combined the costs associated with ceasing agricultural activities and afforesting with the projected carbon to be sequestered from this land use action. Calculating the cost per CO_2e allows the various land management practices to be compared with other mitigation options. Prices per ton of CO_2e will vary dependent on both the costs associated with conversion and the potential carbon sequestration capacity. Marginal costs per ton of CO_2e are lower in pasture land due to the lower opportunity costs (Table 3A-3, Figure 3A-4). Cropland only becomes available for afforestation when marginal costs reach \$40/ton CO_2e (Table 3A-4). Some pastureland will be available at a marginal cost of \$15/ton CO_2e, and the amount of land available increases dramatically as the time interval is extended (Table 3A-4). The area of land and tons CO_2e that could be sequestered at each price point represents the maximum available and assumes that all available land is converted to afforestation when it becomes economically advantageous on that land.

Table 3A-3. Estimated weighted-mean marginal cost per ton of CO_2e sequestered in all northeastern states on crop and pasture land.

	Cropland			Pasture Land		
	10 years	20 years	40 years	10 years	20 years	40 years
	estimated \$/ton CO_2e					
Weighted mean	\$105	\$101	\$105	\$73	\$61	\$58
Minimum	\$39	\$36	\$38	\$15	\$12	\$10
Maximum	\$230	\$248	\$227	\$237	\$257	\$236

Table 3A-4. Estimated maximum potential tons of CO_2e that could be sequestered and area of land that would be available at various prices per ton of CO_2e.

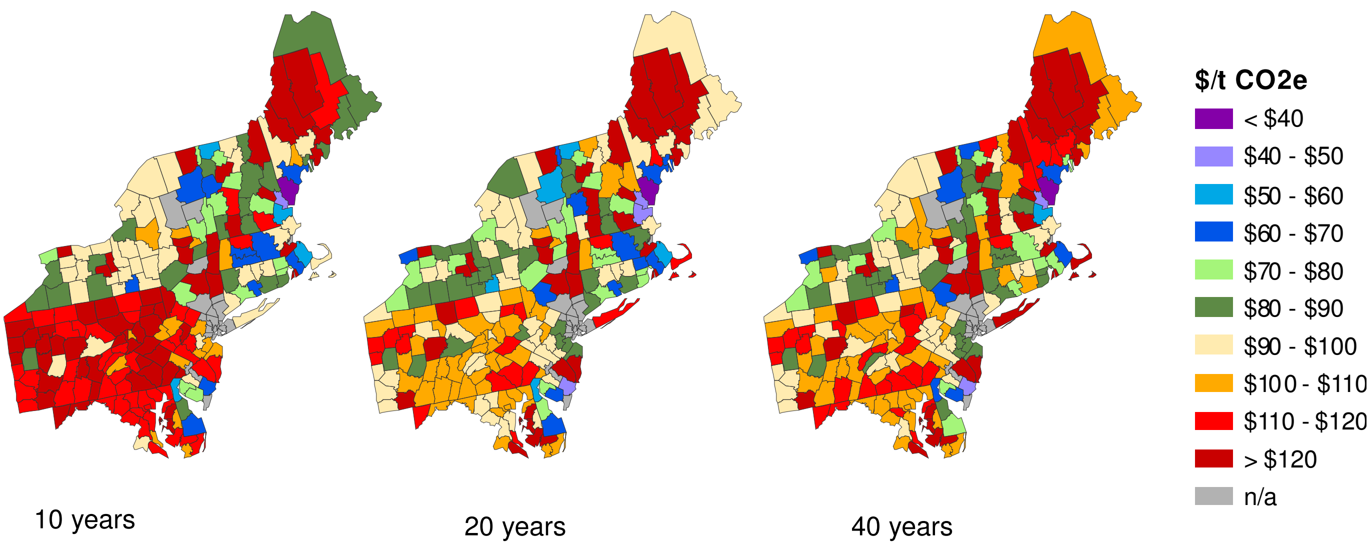
	Estimated maximum potential tons CO_2e					
	Cropland			Pasture land		
	10 years	20 years	40 years	10 years	20 years	40 years
\$7/t CO_2e	0	0	0	141,000	8 million	13.8 million
\$10/t CO_2e	0	0	0	4.7 million	8 million	28.3 million
\$20/t CO_2e	0	0	0	7.5 million	18.9 million	59 million
\$40/t CO_2e	61,000	116,000	191,800	36.8 million	214 million	430 million
\$50/t CO_2e	103,000	344,000	487,000	124 million	324 million	583 million

	Estimated maximum potential available area (acres)					
	Cropland			Pasture land		
	10 years	20 years	40 years	10 years	20 years	40 years
\$7/t CO_2e	0	0	0	3,600	170,000	170,000
\$10/t CO_2e	0	0	0	3,600	170,000	294,000
\$20/t CO_2e	0	0	0	244,000	374,000	582,000
\$40/t CO_2e	1,600	1,600	1,600	1.28 million	3.6 million	4 million
\$50/t CO_2e	2,800	5,000	4,700	4 million	5.5 million	5.6 million

On cropland, Delaware, Massachusetts, and Vermont have on average, the lowest marginal costs while Maryland, Pennsylvania, and New Jersey contain the largest marginal costs on average. Due to the low productivity levels of pastureland, Maine has the lowest marginal costs on pastureland, averaging less than \$40/ton CO_2e for the state (for 20 year period). For pasture land, Rhode Island, Pennsylvania, and Maryland again have the highest marginal costs. However, Maryland, Pennsylvania, and New York have the potential to sequester the most carbon, followed by Maine and Vermont (Figure 3A-5) due to both high sequestration potential and large area available for afforestation.

Overall, the best opportunity for afforestation of agricultural lands is on pastureland in Maine, Vermont, or New Hampshire. This is due to lower pasture productivity levels, and therefore opportunity costs but average afforestation carbon sequestration potential and large areas of available land.

Cropland:



Pasture land:

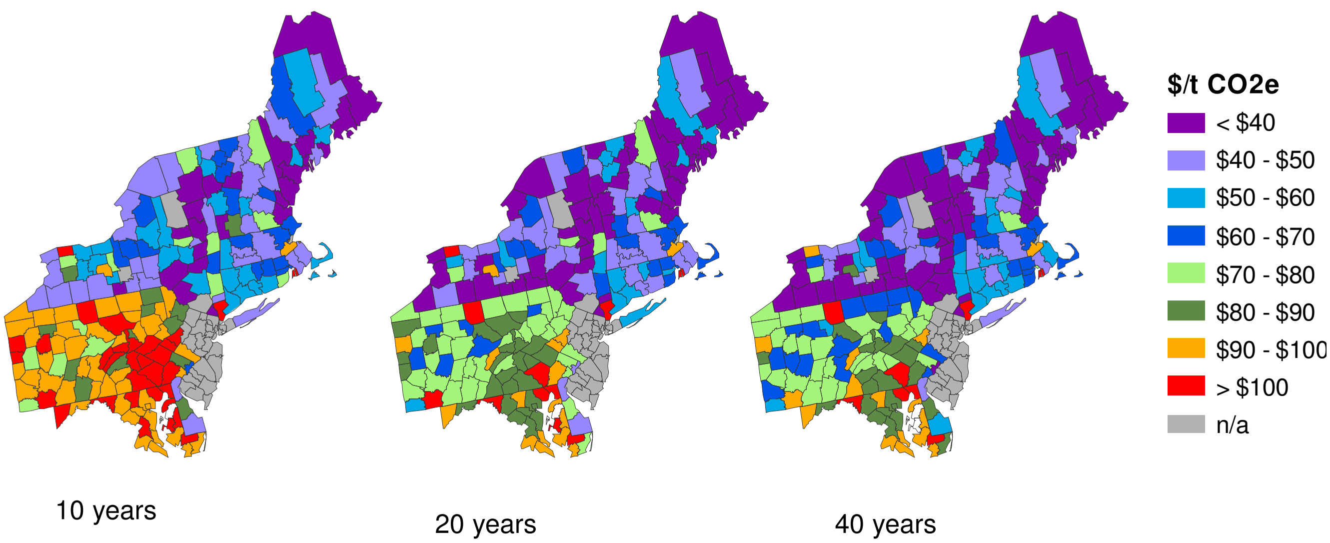
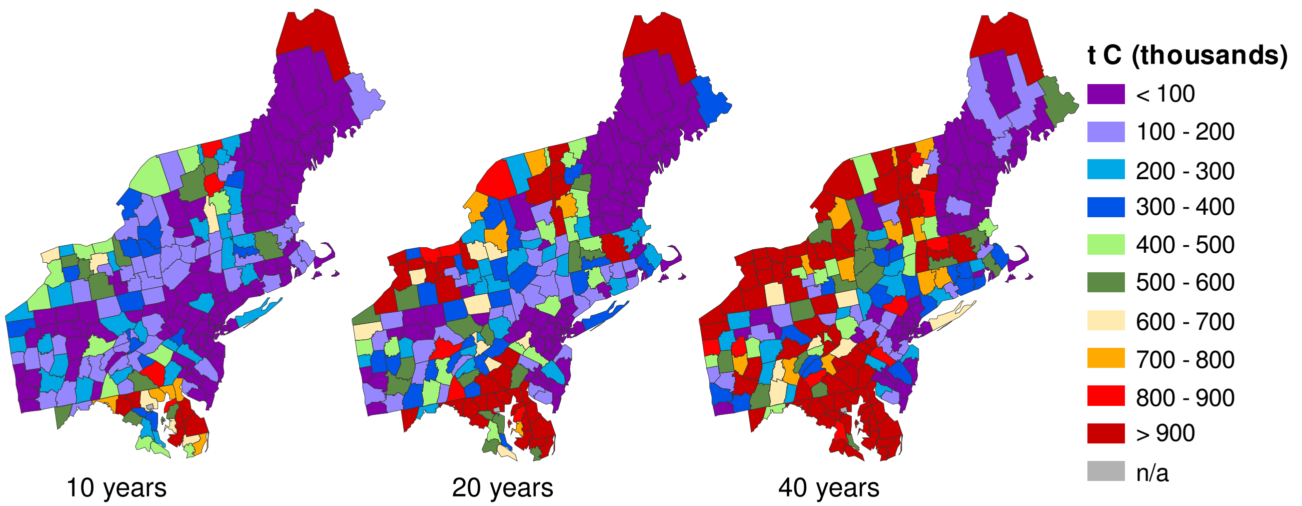


Figure 3A-4. Estimated marginal costs ($/t CO_2e) for carbon sequestration by afforestation of both cropland and pasture land.

Cropland:



Pastureland:

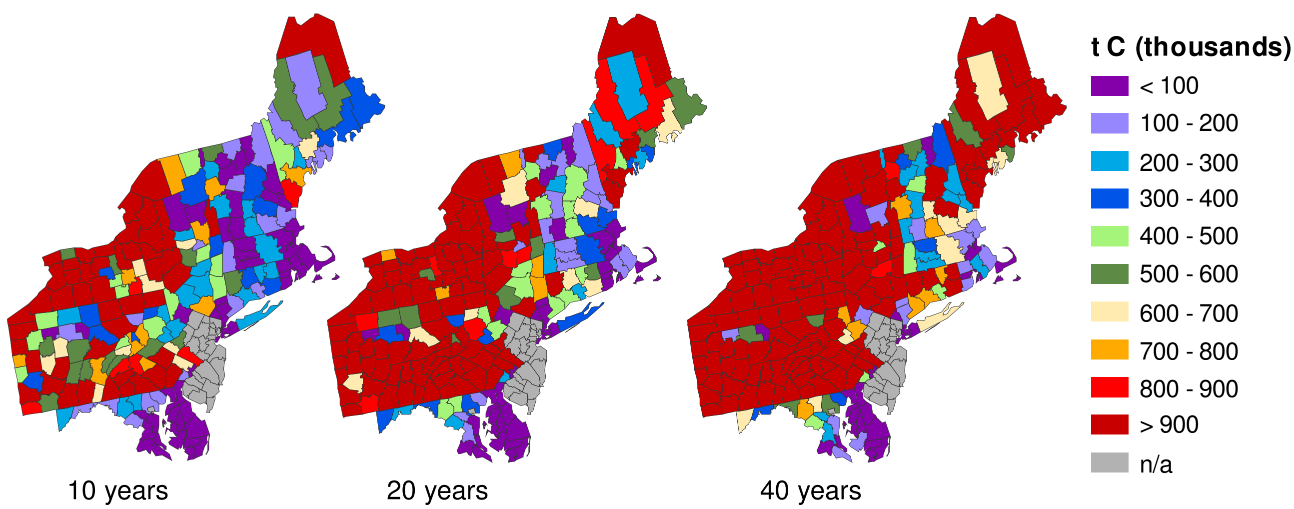


Figure 3A-5. Estimated maximum total quantity of carbon sequestered, in thousands of tons, on crop and pasture lands for each county

3A.2 Introduction

Estimates of carbon storage potential in the United States have generally been based on simple biological and technical criteria without consideration of the economic costs associated with changing land management practices or of the varying carbon sequestration potentials across diverse landscapes. Incorporating the varying carbon sequestration potential of different land classes and other economic factors will yield more realistic estimates of carbon storage potential. Estimates of a more realistic potential for carbon sequestration from changes in land use can help companies prepare for an uncertain regulatory future by providing estimates of the quantity of carbon credits that would potentially be available at different price points for different classes of projects. The carbon estimates can also help corporations prepare a portfolio of potential responses for a range of future climate scenarios. The report and the data layers developed to produce this report also show where the least expensive credits will most likely be found.

The overall goal of this regional study was to investigate the potential of increasing terrestrial carbon storage as a climate mitigation strategy on lands in 11 states of the Northeast USA. The study generates estimates of the potential carbon sequestration supply in the region associated with afforestation along with the estimated costs associated with land use conversion (Figure 3A-6). The analyses identify the areas for potential low costs per CO_2e for afforestation. The analyses are performed spatially at a county level scale of resolution. Every attempt was made in each stage of the analyses to create a methodology that was reproducible at the national scale, incorporating data sets that are available in every state.

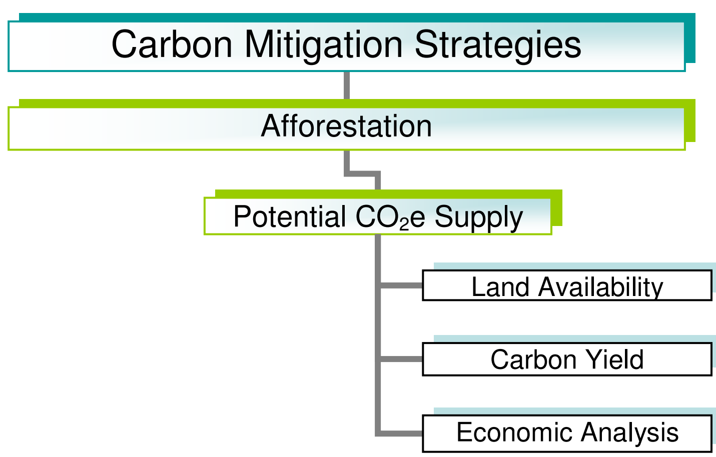


Figure 3A-6. Flow chart displaying overall steps to estimate carbon supply

The Northeastern region of the United States was historically dominated by forest cover (see Part I of this report). Most non-wetland areas of the region are able to sustain forests. Over the last 200 years, forest cover has again come to dominate the region and although forests do cover 67% of the land area, there are still opportunities to increase carbon stocks through afforestation of existing non-forest land.

3A.2.1 Approach and Methods

The main goal of this study was to estimate the carbon supply for afforesting existing croplands and pasture lands. The analysis employs both spatial data such as land cover maps and tabular data, reported at county scales, such as USFS Forest Inventory and Analysis (FIA) databases and USDA NRI and NASS data bases. The analysis incorporates information about current land use, potential changes in land use and the incremental carbon resulting from the change, opportunity costs, conversion costs, annual maintenance costs, and measurement and verification costs. The analysis is performed in a geographic information system (GIS), allowing for a spatial representation of the potential mitigation strategy, rates of carbon sequestration, and costs in the analyses. As a result, not only are more realistic estimates of the potential supply of carbon produced, but the use of GIS illustrates where the least to most expensive carbon credits will most likely be found. All analyses were done at the county-level scale of resolution. The sources of the databases used in this analysis can be found in the 'Data Sources' section below and in the References section at the end of this report. Land cover maps, based on remote sensing imagery, for each state form the basis of this analysis. The land cover estimates in Part II of this report (Recent Trends in Sinks and Sources) used the National Resources Inventory (NRI) data base and as a result, the absolute area estimates in that part are different from those obtained here.

3A.2.1.1 Overall method for estimating the carbon supply

The following steps were used to assess the quantity and cost of potential carbon sequestration through afforestation:

1. Classify lands found in the region by harmonizing existing state-level land cover maps.
2. Identify the major land cover types with potential for carbon sequestration.
3. Estimate the area available for each potential land use change by each county within the 11 states.
4. Estimate the total costs associated with land use conversion (opportunity, conversion, maintenance, and measuring and monitoring).
5. Estimate the quantities of carbon per unit area that could be sequestered for the change in land use over a given time period for each county within the 11 states.
6. Combine the estimated sequestered carbon per unit area with corresponding land cover class to estimate the total quantity of carbon at the county scale that could be sequestered using each land use category for a given range of costs in \$/ton CO_2e.
7. Determine the geographic distribution, at the county scale of resolution, of available carbon at various prices.

The carbon supply for each carbon mitigation strategy is estimated for three time durations – 10 years, 20 years and 40 years – to reflect the impact of duration on supply and to provide an assessment for the near–term and longer-term planning horizons (Figure 3A-7).

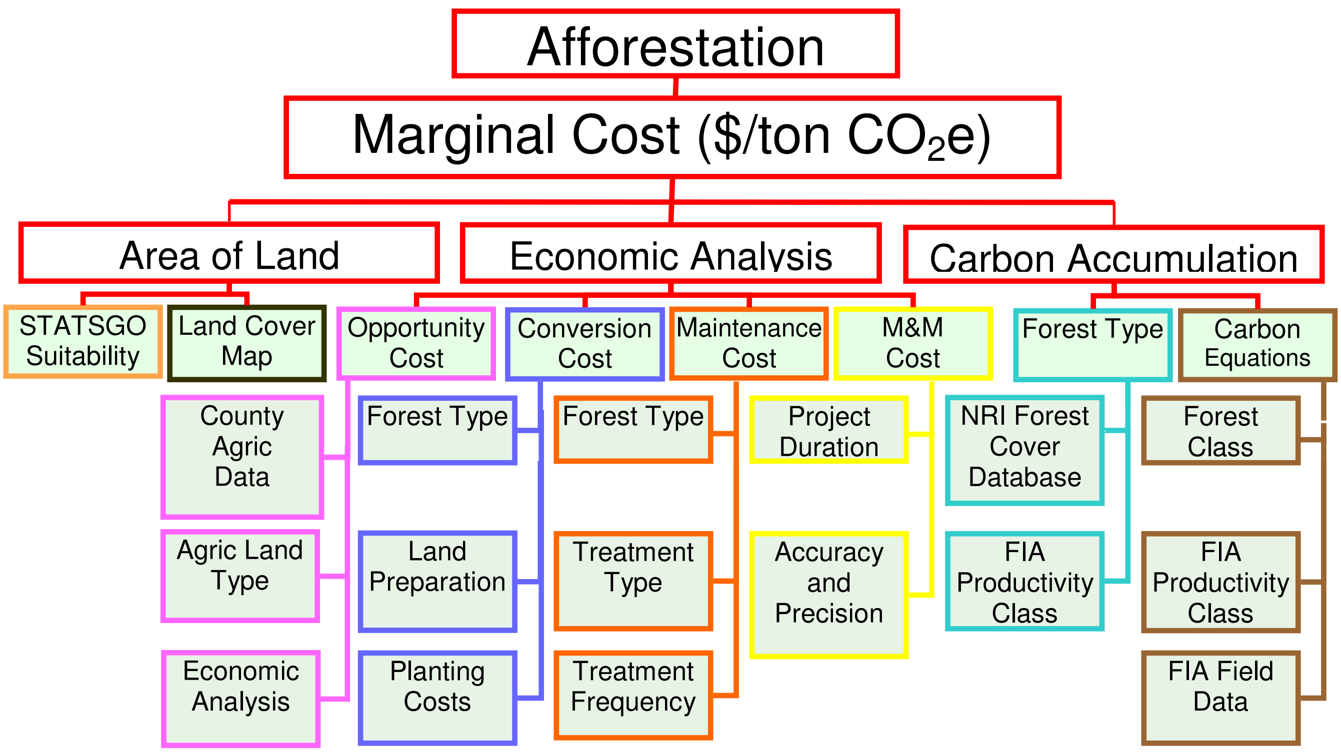


Figure 3A-7. Illustration of the steps involved in generating the carbon supply curves for afforestation of agricultural lands.

3A.2.1.2 Data sources

This study used a wide variety of spatial and non-spatial data sets. The data for the geographic analysis were downloaded off state agency web sites. The spatial data sources are:

- Connecticut Department of Environmental Protection - *Land Use and Land Cover Mapping for the Connecticut and New York Portions of the Long Island Sound Watershed*. This is based on LANDSAT Thematic Mapper Satellite Imagery and SPOT Panchromatic Satellite Imagery for 1994 and 1995. The resolution is 30 meters. The minimum mapping unit is 1 hectare. There are 28 land use categories.
- Delaware Office of State Planning - *2002 Land Use and Land Cover Data.* Based on the 1997 land-use data of the State and 2002 false color infrared digital orthophotography at a scale of 1:2400.
- Maryland Department of Planning - *2002 Land Use / Land Cover for Maryland.* Developed using high altitude aerial photography and satellite imagery, land cover types were updated using 2002 aerial photography for Central Maryland. Urban land use categories were refined using parcel information.
- Massachusetts Executive Office of Environmental Affairs - *MassGIS Land Use 2002.* The dataset has 37 land use classifications interpreted from 1:25,000 aerial photography. Coverage is complete statewide for 1971, 1985, and 1999. Additionally, more than half the state was interpreted from aerial photography flown during 1990, 1991, 1992, 1995 or 1997.
- Maine Office of Geographic Information System - *Land Cover and Wetlands of the Gulf of Maine.* Land cover from five interpretations of Landsat data, and wetland cover from photo-interpretations were combined to yield a 31-class raster coverage, for the Gulf of Maine watershed. The resolution is 30 meters.
- University of New Hampshire, EOS-WEBSTER Earth Science Information Partner - *New Hampshire Land Cover Assessment – 2001.* The New Hampshire Land Cover Assessment categorizes land cover and land use into 23 classes, based largely on the classification of Landsat imagery. The resolution is 30 meters.
- New Jersey Department of Environmental Protection - *1995/97 Landuse/Landcover by Watershed Management Area.* Created by comparing the 1986 LU/LC layers from the NJDEP GIS database to the 1995/97 color infrared digital imagery, and delineating areas of change.
- Rhode Island Department of Administration - Statewide Planning Program - *1995 Land Use edition 2c.* Updated using 1995 USGS DOQs from a similar RIGIS Land Use data set generated in 1988 as the update vector base source.
- Vermont Center for Geographic Information - *LandLandcov_LCLU2002.* This dataset was derived by classifying independently three 2002 Landsat-7 ETM+ scenes, supplemented by ancillary data sources. The resolution is 30 meters.
- USGS Seamless Data Distribution System, Earth Resources Observation and Science - *USGS National Land Cover Data (NLCD).* NLCD 92 is a 21-category land cover classification scheme that has been applied consistently over the conterminous U.S. It is based primarily on Landsat 1992 imagery. Ancillary data sources included topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data. The resolution is 30 meters.
- ESRI county and state datasets – Administrative polygons of state and county boundaries, originally created for the Digital Chart of the World. The Digital Chart of the World (DCW) is an Environmental Systems Research Institute, Inc. (ESRI) product originally developed for the US Defense Mapping Agency (DMA) using DMA data. We used the DCW 1993 version at 1:1,000,000 scale.

Non-spatial data sources included:

- US Forest Service Forest Inventory and Analysis (FIA) data
- Natural Resources Inventory (NRI)
- Volume to biomass equations from USDA Forest Service
- Harvested crop acres and yields by county for each state from USDA National Agricultural Statistics Service (NASS)
- Estimated future crop prices for 2006-2015 from the Food and Agriculture Policy Research Institute (FAPRI)
- Historical crop price data by state from USDA-NASS
- Cost of production data from USDA Economic Research Service (ERS)

The details of all of these data and their applications are given in the appropriate sections below.

3A.2.1.3 Scale of analyses

The analysis of land cover and carbon storage potential in the GIS was carried out at the county scale. A total of 243 counties exist in the eleven states. Baltimore city was separated from Baltimore county in the ESRI dataset of counties and was left separate during the analysis. New York and Pennsylvania did not have available a current landcover dataset; thus the National Land Cover Dataset from 1992 was used for these two states. An updated National Land Cover Dataset for the entire United States is scheduled for release at the end of 2006 by the USGS. Efforts to obtain advanced copies from the USGS of the landcover data for the Northeast region have not been successful. For Connecticut, an older landcover dataset from 1995 was used rather than the current 2003 state landcover dataset because that current version only contains the overly general landcover category agriculture while the older dataset breaks down agriculture into crop and pasture categories. Also, in New Jersey, the landcover dataset contains several cropland categories but no pasture or hay category. As a result, no pasture land for New Jersey was considered in the analysis.

3A.3 Availability of land for carbon sequestration

3A.3.1 Classification of lands

Using the most suitable land cover maps described above, the land cover classification schemes were harmonized and compiled into four classes relevant to this project: forest, pasture land, cropland, and other (Table 3A-5). The cropland category was created by aggregating and renaming the categories of small grains, row crops, or fallow lands. The pasture land category came from the pasture, hay, & other grasses categories. The resulting classification of pasture lands and croplands were compiled.

Table 3A-5. Land cover definitions

Class	Definition
Cropland	small grains, row crops, fallow lands
Pasture	pasture, hay, & other non recreational grasses
Forest	mixed, deciduous, coniferous, clear cuts, woody wetlands
Other	Other is any category that is not cropland, pastureland or forest. The categories vary by state, but in general are urban, commercial, recreational, water, and other types of agricultural not in our study. Some examples categories are; commercial, industrial, residential, water, wetlands, tidal areas, orchards, confined feeding operations, barren, utility right of ways, recreational grasses, cranberry bogs, transitional, truck crops, military reservations, athletic fields, and cemeteries.

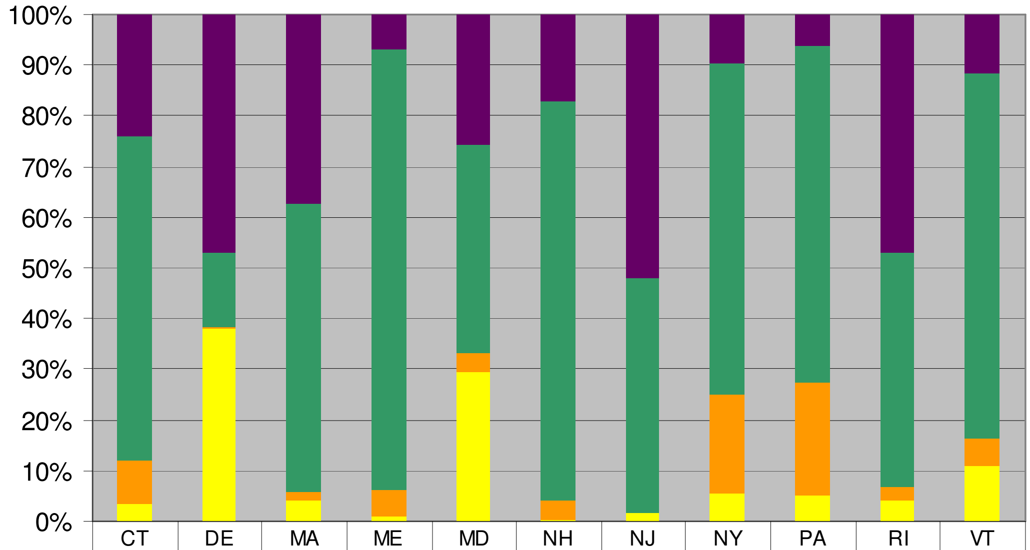
3A.3.2 Estimate of available land areas

This region is dominated by forest lands. Croplands and pasture lands make up only 6 and 13% respectively of the total land area in the region (Table 3A-6, Figure 3A-8, 3A-9, 3A-10). Delaware and Maryland have a greater percentage of cropland, with cropland covering 38 and 28% of the land respectively. Pasture land in Pennsylvania and New York are above the regional level at 22 and 19%, respectively. New Jersey does not provide a land cover dataset with pasture as a distinct category. The land use, land cover datasets provided by New Jersey combine cropland and pastureland into a single category. While it was possible to parse cropland out of the dataset using other categories in the dataset such as fallow fields and agricultural wetlands, it was not possible for pastureland. Therefore, that category was excluded from analysis in New Jersey.

Table 3A-6. Area of agricultural land in each state of the region.

	Total area		Pastureland		Cropland		Forest		Other	
	(ha)	(acre)	(ha)	(acre)	(ha)	(acre)	(ha)	(acre)	(ha)	(acre)
Connecticut	1,288,912	3,184,902	109,585	270,785	44,892	110,927	822,934	2,033,515	309,737	765,378
Delaware	532,130	1,314,892	1,483	3,665	203,565	503,010	77,715	192,038	250,865	619,902
Maine	8,329,748	20,582,808	403,914	998,072	86,479	213,690	7,250,693	17,196,852	571,569	1,412,379
Maryland	2,522,615	6,233,381	88,978	219,866	716,437	1,770,317	1,043,347	2,578,167	645,043	1,593,936
Massachusetts	2,116,664	5,230,277	37,015	91,464	90,060	222,538	1,200,327	2,966,073	793,203	1,960,049
New Hampshire	2,398,169	5,925,876	89,382	220,863	6,213	15,353	1,891,001	4,672,765	412,017	1,018,117
New Jersey	1,944,424	4,804,672	-	-	33,827	83,586	908,265	2,244,373	1,022,799	2,527,393
New York	12,577,284	31,078,468	2,437,036	6,021,915	707,382	1,747,942	8,247,897	20,380,997	1,201,247	2,968,346

	Total area		Pastureland		Cropland		Forest		Other	
	(ha)	(acre)	(ha)	(acre)	(ha)	(acre)	(ha)	(acre)	(ha)	(acre)
Pennsylvania	11,748,134	29,029,639	2,641,700	6,527,641	582,283	1,438,822	7,774,332	19,210,794	737,681	1,822,850
Rhode Island	270,621	668,704	6,074	15,009	10,236	25,293	126,555	312,725	127,462	314,965
Vermont	2,487,200	6,145,872	124,683	308,092	231,682	572,485	1,788,201	4,418,742	287,903	711,425
All States	46,215,901	114,199,491	5,939,850	14,677,372	2,713,056	6,703,963	31,131,271	76,927,048	6,359,531	15,714,745



	CT	DE	MA	ME	MD	NH	NJ	NY	PA	RI	VT
Other	24.03%	47.08%	37.41%	6.87%	25.52%	17.17%	52.05%	9.55%	6.28%	46.82%	11.57%
Forest	63.85%	14.59%	56.60%	87.10%	41.28%	78.79%	46.22%	65.58%	66.18%	46.49%	71.86%
Pasture	8.59%	0.27%	1.74%	4.99%	3.58%	3.78%		19.42%	22.58%	2.60%	5.66%
Cropland	3.52%	38.06%	4.25%	1.05%	29.62%	0.27%	1.72%	5.45%	4.97%	4.09%	10.92%

Figure 3A-8. Percentage of total area of each state by the main land cover classes

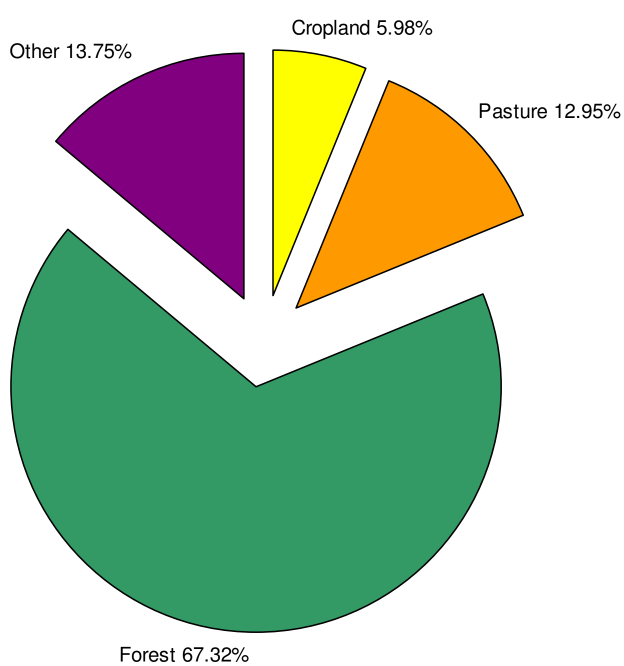


Figure 3A-9. Distribution of land cover classes for the total region.

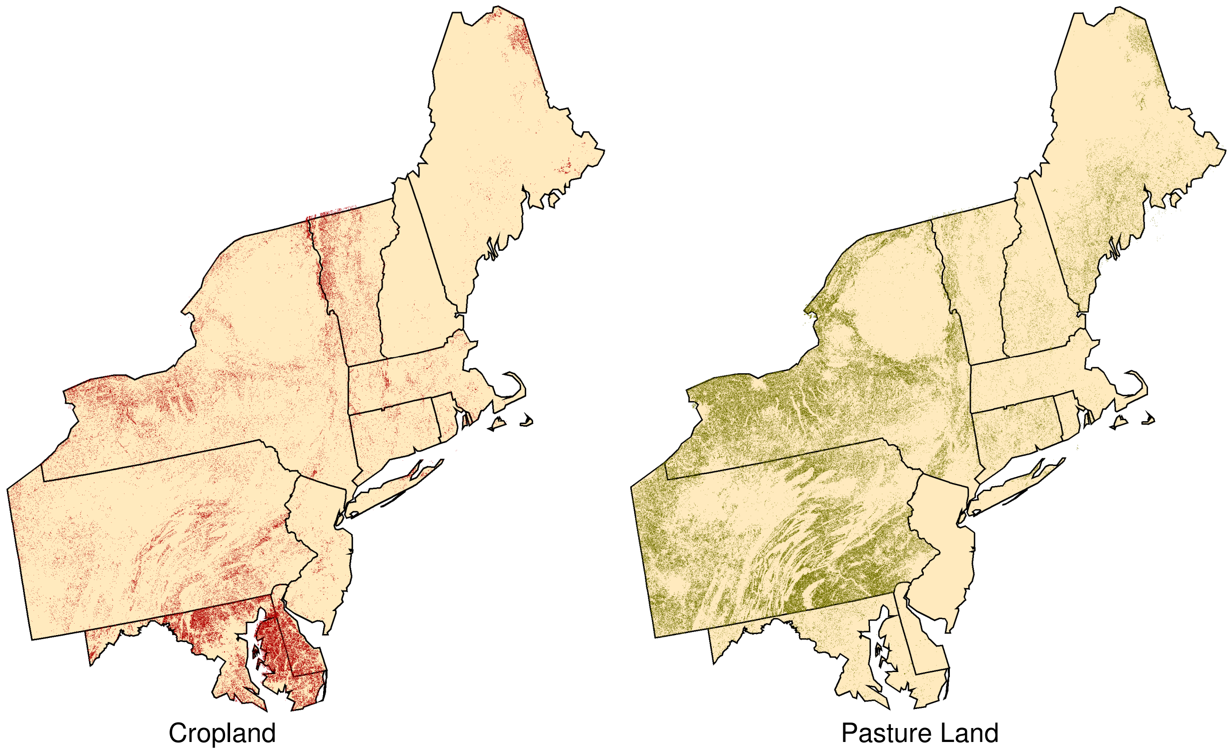


Figure 3A-10. Land cover of cropland and pasture in the northeast region

3A.4 Economic analysis and total costs

The economic analysis employs four cost categories: Opportunity, Conversion, Maintenance, and Measuring & Monitoring Costs. Each cost category is described in the sections below. In the economic analysis, we are interested in ascertaining the "price" a farmer would need to receive to take a parcel of land out of agriculture and put it in some carbon sequestering use. That "price" must be equal to or greater than the return the farmer is currently receiving from the agricultural use of that land plus the associated costs incurred in producing certified carbon offset credits. Therefore, the "price" will have to be equal to or greater than the marginal return to the farmer from the parcel of land under consideration (i.e. Opportunity Cost) plus the Conversion, Maintenance, and Measuring & Monitoring Costs. That marginal return is the estimated revenue less the variable (i.e. input) costs for the agricultural enterprise in question.

For interpreting this analysis, it is important to understand the difference between variable and fixed costs. Fixed costs (FC), also known as overhead costs, are those expenses that would continue to be incurred in the short-run, even if crops were not planted and/or production was zero. Examples of FC include property taxes and machinery ownership costs. By contrast, variable costs (VC) are those expenses that are a direct result of the production process. Examples of VC include fertilizer, herbicides, labor, and fuel. Fixed costs are not considered in this analysis for two important reasons. First, farmers would continue to incur land ownership costs. Second, it is unlikely that a farmer would enroll all land in a carbon sequestration project, but only selected fields or parcels. Fixed costs for the farm, therefore, would remain the same.

3A.5 Opportunity costs

The most significant cost category in this analysis is the opportunity costs. All economic decisions involve trade-offs. If activity X is forgone in order to undertake activity Y, then the value of undertaking activity X must be considered as the opportunity cost of undertaking activity Y. Simply put, the opportunity cost is the most highly valued alternative to the activity being considered. In this case, the activity being considered is afforestation of agricultural land in 11 Northeastern states. Therefore, the profitability per hectare of agriculture in each county represents the opportunity cost of producing carbon on that land (i.e. afforestation). The ultimate cost of producing carbon on agriculture land is going to differ from field to field and county to county, primarily based on the quality of the soil and growing conditions, which directly influences both agricultural yields (i.e. opportunity costs) and carbon yields (i.e. afforestation).

The economic analysis methodology used here for estimating the opportunity costs of afforestation projects on agricultural land is based on widely available data on prices, costs, and yields of the major crops produced in each state in the region. This methodology was intentionally designed to be easily replicable across states. In doing so, some degree of local specificity regarding costs and prices of crop production were foregone, but the simplicity and replicability of this approach outweighs the small margins of error caused by using regional cost and price data.

The dominant agricultural land uses for the region as a whole are corn, hay/pasture, and soybeans (Table 3A-7). With corn and hay each comprising approximately 4 million acres; soybeans are a distant third with just over 1.4 million acres harvested annually. The area planted to wheat is just under 500,000 acres, while oats and barley each occupy less than 200,000 acres throughout the region. These data were collected from the USDA National Agricultural Statistics Service (NASS). Based on these data, our analysis focuses on corn and soybean production to estimate the representative profitability for cropland in region. Hay production is used to estimate the profitability of pasture land. Although pasture land will have highly variable opportunity costs, using the profitability of hay production in each county provides a proxy that is not likely to underestimate the value of pasture land. This approach provides a solution to the problem of estimating the actual profitability of pasture land, which can support many different species of livestock or be left fallow. Additionally, a significant amount of hay is produced from pasture land.

It is important to note that crop rotation is a common agricultural practice throughout the Northeast, as well as in other regions. Therefore, very little agricultural land that is used for crop production (i.e. not permanent hay or pasture land) produces the same crop each year. In the states where soybeans are produced (the southern part of the Northeast region), a multi-year rotation is often used that consists of corn (a heavy user of nitrogen), soybeans (a legume crop that fixes nitrogen into the soil), and/or a cover crop, which is usually alfalfa or a mixture of alfalfa and grasses. The average acreages planted to each crop in any given county across numerous years should provide a fairly accurate picture of the relative importance of each crop in that county. Agricultural land that is not suitable for tillage (i.e. land that is too marginal, rocky, or steep) is often used for permanent hay and/or pasture land. This land will generally not produce the high quality alfalfa hay that is included in the rotation on cropland, as alfalfa requires tilling for re-establishment every 5-7 years. Permanent hayland will generally produce grass hay that consists of native species, such as orchard grass, timothy, brome, and/or other species.

Table 3A-7. Area of crops planted by state (based on NASS dataset).

	Corn	Soybeans	Hay	Wheat (Acres)	Oats	Barley	Potatoes
Connecticut	59,000	0	66,000	0	0	0	0
Delaware	160,000	210,000	14,000	50,000	0	29,000	3,300
Massachusetts	37,000	0	88,000	0	0	0	2,600
Maryland	490,000	500,000	215,000	160,000	0	42,000	4,700
Maine	24,177	0	171,280	n/av	n/av	n/av	n/av
New Hampshire	14,191	0	55,948	n/av	n/av	n/av	n/av
New Jersey	99,000	105,000	120,000	28,000	0	3,000	2,300
New York	1,450,000	175,000	1,270,000	105,000	65,000	14,000	20,000
Pennsylvania	1,400,000	430,000	1,980,000	140,000	130,000	65,000	12,000
Rhode Island	4,000	0	9,000	0	0	0	500
Vermont	185,000	0	230,000	n/av	n/av	n/av	n/av
Total	3,922,368	1,420,000	4,219,228	483,000	195,000	153,000	45,400

Profits, or marginal returns (MR) to the land, per area of land can be calculated with the expression, $MR = PY - CY + G$;

where P is the price per unit for each commodity received by the farmer, Y is the expected yield of that crop, C is the variable cost of production per unit, and G is the amount of money received as government payments or subsidies for producing that crop.

Prices

For farmgate prices for corn, soybeans, and hay, estimates developed by the Food and Agriculture Policy Research Institute (FAPRI) were used (FAPRI, 2005). The estimates are created for each commodity for each year through 2015. A mean of the estimates from 2006 through 2015 was used. These estimates are developed as national averages for the U.S. for all leading agricultural commodities. To tailor these estimates for each of the 11 states in the region, a historical price differential between the average U.S. price and the average state price from 1980-2005 was calculated and applied. The time-series data on average state farmgate prices was obtained from the USDA National Agricultural Statistics Service (NASS). The differential for each crop for each year was calculated and averaged across the 25 years. This average differential was used to adjust the national average price projections to be used for each state (Table 3A-8).

Table 3A-8. Estimated average national and state crop prices (2006-2015).

	Corn	Soybeans	Hay
National Average	$2.23	$5.28	$92.22
Connecticut	$2.56	$5.28	$130.34
Delaware	$2.54	$5.33	$123.47
Massachusetts	$2.56	$5.28	$100.95
Maryland	$2.55	$5.32	$122.22
Maine	$2.56	$5.28	$128.74
New Hampshire	$2.56	$5.28	$125.28
New Jersey	$2.48	$5.21	$120.53
New York	$2.56	$4.94	$98.80
Pennsylvania	$2.64	$5.24	$116.05
Rhode Island	$2.56	$5.28	$134.76
Vermont	$2.56	$5.28	$107.82

Yields

Historical crop yield data are available at the county level from USDA-NASS. For the states where annual yield data was available (all excluding New England states), an average of yields from 2000 through 2004 were used. For the New England states, yields from the 2002 Census of Agriculture were used. The variation in these county-specific yields (Table 3A-9) provided a significant amount of the variation in opportunity and total C costs within the states and across the region.

Table 3A-9. Mean yields and crops for each state.

	Corn (bushels/acre)	Soybeans (bushels/acre)	Hay (tons/acre)
Connecticut	103.53	n/app	1.96
Delaware	129.52	33.55	2.35
Massachusetts	95.43	n/app	1.64
Maryland	124.34	35.16	2.53
Maine	103.78	n/app	1.96
New Hampshire	108.77	n/app	1.77
New Jersey	109.85	31.79	2.13
New York	111.06	32.69	2.16
Pennsylvania	110.17	38.23	2.31
Rhode Island	93.64	n/app	1.99
Vermont	92.91	n/app	1.92

Costs of Production

The variable costs of production for corn and soybeans are taken from estimates created by the USDA Economic Research Service (ERS) for the "Northern Crescent" region (USDA Economic Research Service, 2005). This region corresponds fairly well with the Northeastern states. Because ERS does not produce cost of production estimates for hay, this analysis has used estimates produced by Penn State University (Penn State University, 2006). The variable cost of production estimates are based on specific yield level per acre. To increase the accuracy of these estimates across the range of yields in this analysis, the VC estimates for each county as a function of the county average yield were adjusted. It is important to note that not all VC fluctuate with yields; fuel costs are an example of this. However, fertilizer is one of the larger segments of VC and fertilization rates are usually based on an expected yield for a given field or area. Therefore, for yields that are at least 10% different from the average, the VC was adjusted in the same direction by 5%. For yields that are more than 20% different, VC were adjusted by 10%.

Government Payments

Corn and soybean production are both eligible for government subsidy payments (hay and pasture production are not eligible). There are three primary payment vehicles; these are direct, counter-cyclical, and loan deficiency payments. Each payment type has its own calculation formula. For each commodity there are specific price targets, payment levels, and caps. For direct and counter-cyclical payments, up to 85% of a farm's acres are eligible.

Direct payments are made to farmers each year regardless of the yield or price levels. The payment rates are $0.28 per bushel for corn and $0.44 per bushel for soybeans. This is essentially a price premium paid to all farmers nationwide, regardless of the final use of the commodity. The total direct payment per acre increases with yield.

Counter-cyclical payments (CCP) are calculated with a more complex formula than are direct payments. The CCP is triggered by an official national average price for the commodity. If the national average price in a given year is less than the target price set for the commodity ($2.63 per bushel for corn and $5.80 per bushel for soybeans) minus the direct payment level per bushel, then the CCP is calculated as the lesser of this number and the maximum CCP per bushel set for each commodity. This maximum is $0.34 per bushel for corn and $0.36 for soybeans. Therefore, the CCP is designed to come into effect in years when a commodity's price is depressed. Like direct payments, CCP per acre will increase with yield. Because the CCP is triggered by the national average price for a commodity, it is possible for farmers in a region to receive a market price above the target price and still receive the CCP.

Loan deficiency payments (LDP) take effect when the price received by the farmer is less than the government established loan rate for each commodity. This loan rate is currently $1.95 per bushel for corn and $5.00 per bushel for soybeans.

Calculation of Opportunity Costs

Based on the information provided above, the opportunity costs per acre are calculated for the production of each commodity on representative cropland in each county of the 11 states of the region. The formula used to calculate this is the revenue received less the VC per acre plus the applicable government payments. The revenue is the price received (state average adjusted for historical differential) multiplied by the yield (county average). The VC per acre is the yield multiplied by the VC per bushel. The government payments are the sum of the direct, counter-cyclical, and loan deficiency payments, as calculated for each county.

The opportunity cost of producing corn will differ from the opportunity cost of producing soybeans. In practice, these crops will be grown on the same land in a rotation that often includes some years of alfalfa or other forage crop. The relative number of acres in corn versus soybeans in any given county varies across counties and states. Soybeans are generally not produced in the New England states (Table 3A-9). Therefore, to calculate spatially-explicit (to the county level) and more accurate estimates of opportunity costs, this analysis employs a weighting of the opportunity costs for corn and soybeans within each county. This weighting is based on the average percentage of cropland in each county that is planted with corn relative to the percentage that is planted with soybeans. These percentage weights for each county are calculated as an average over 2000 through 2004 with data from USDA. However, as described in the Yields section above, annual data were not available for the New England states and data from the 2002 Census of Agriculture for each state were used in its place.

Opportunity costs vary by state, however the average present value of the opportunity cost on cropland in the region for a ten-year C project was $1,300 per acre. This represents the foregone income over variable costs of production in each of ten years, discounted into current dollars. For pasture land, the regional average for a ten-year project was $690 per acre (Figure 3A-11). The opportunity costs for Maine pasture land are much lower than the other states in the region, averaging less than $200/acre for a ten year project. This reflects the NASS data that reports hay yields in Maine as significantly lower than in other states.

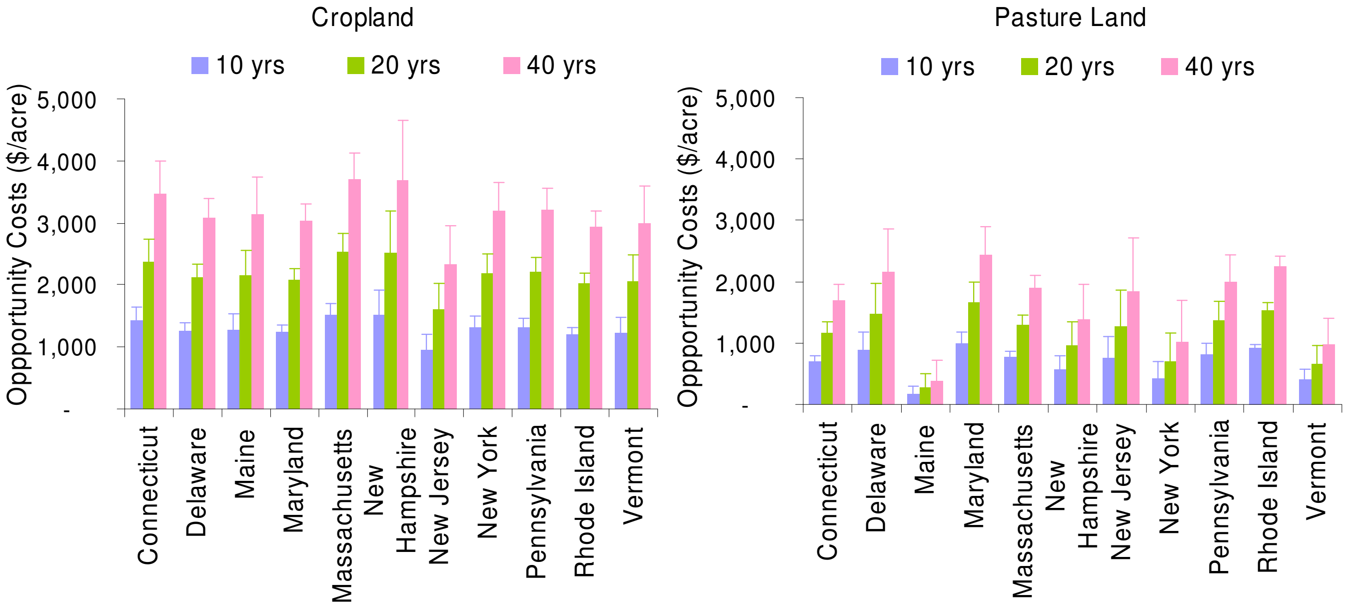


Figure 3A-11. Average opportunity costs for each state for both cropland and pasture land.

3A.5.1 Afforestation costs

3A.5.1.1 Conversion and maintenance costs

Conversion and maintenance costs are those associated with land preparation, planting, maintenance, and herbivory protection where needed. To estimate these 'conversion costs', a simple survey of tree planting costs was prepared and sent to regional foresters by state or other foresters and related specialists in the US Forest Service, universities, or forest companies in the 11 Northeast states. Data were collected by direct contact, by phone, e-mail, or from publications of forestry institutions (Appendix 1).

Information collected included costs for both hardwood and softwood planting. Costs included: a) Site preparation costs, such as removal of competing vegetation, seedbed preparation (mowing, tillage and herbicide application) b) Planting costs, such as plant cost, labor for plant, shelters and mats, shipping and handling, hand planting vs. mechanic c) Maintenance costs, such as weeding, mowing, herbiciding, tilling, etc., herbivore control like deer and other. D). Replanting costs, including minimum survival rate in trees per area. The largest variable in the conversion costs is herbivory protection and mechanical site preparation (Table 3A-10). Estimates of maximum costs include installing deer herbivory protection such as fencing in states where it was recommended and mechanical site preparation. From the survey, Pennsylvania was the state where the most deer protection is needed. These costs are an initial one-time cost and therefore will be independent of the length of the project period. Compiled information on deer densities (Figure 3A-12) also shows Pennsylvania to support the largest deer populations in the region, based on the density of deer harvest.

Table 3A-10. Conversion and maintenance costs associated with afforestation activities for each state. Costs include site preparation, labor, seedlings, and herbivore protection.

	Hardwood ($/acre)			Softwood ($/acre)		
	Min	Max	Average	Min	Max	Average
Connecticut	400	1000	700	400	1000	700
Delaware	260	700	480	270	700	485
Maine	450	750	600	350	650	500
Maryland	950	1410	1180	700	1160	930

	Hardwood ($/acre)			Softwood ($/acre)		
	Min	Max	Average	Min	Max	Average
Massachusetts	500	700	600	350	700	525
New Hampshire	500	500	500	350	500	425
New Jersey	500	500	500	350	700	525
New York	500	600	550	500	600	550
Pennsylvania	980	1600	1290	1000	1650	1325
Rhode Island	600	600	600	375	600	488
Vermont	500	500	500	350	500	425

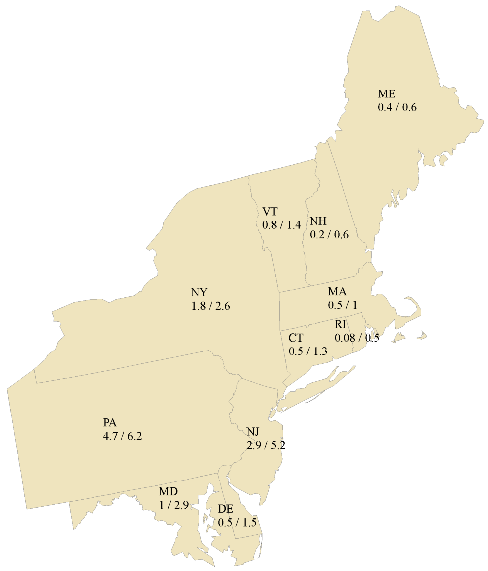


Figure 3A-12. The harvest of antlered white-tailed deer (number per square mi or 259 ha of deer range) in 11 northeastern states in 1983 (first value) and in 1992 (second value) (adapted from Storm and Palmer 1995)

3A.5.1.2 Monitoring costs

Monitoring costs vary with size of the area being monitored, whether the total area is one large block or disaggregated into smaller parcels, the expected variation in the carbon stocks, the pools being monitored, and the frequency of monitoring. For the analysis presented here, it was assumed a typical "project" would be 1,000 acres (400 ha), with disaggregated parcels, with an expected coefficient of variation of the carbon stocks of 30%, monitoring only above and below biomass of the trees, and a monitoring event of every 5 years. Expert opinion (based on Winrock's experience of work on several real projects) of associated costs were compiled and applied. The net present value of the monitoring activities (assuming a net discount rate of 4%) is as follows: $20.6/ac ($50.9/ha) for 10 yr; $29.0/ac ($71.7/ha) for 20 yr; and $38.7/ac ($95.6/ha) for 40 yr.

3A.5.2 Total Costs

Each of the cost categories described above have been incorporated into a total present value cost for afforestation of agricultural land across the region. The weighted annual opportunity cost for cropland and pastureland in each county was discounted over the life of the carbon project (10, 20, and 40 years). A real (i.e. adjusted for inflation) discount rate of 4% was used in the analysis (see discussion of discounting in Part 4 for more details). This present value opportunity cost represents the stream of annual marginal returns to the farmer, in current dollars, from crop or pasture production over the life of the carbon project. Discounting is used to account for the time-value of money as well as the uncertainty of future events related to agricultural production.

This estimated present value cost could be viewed as the minimum amount necessary to induce landowners to afforest agricultural land. However, the reduced risk associated with a carbon contract relative to the various risks inherent in agricultural production could make this cost estimate greater than the minimum amount necessary for more risk adverse land owners to pursue carbon projects. When quantitative information on risk aversion becomes available, a risk aversion factor is built into this analysis and can be applied.

The costs are variable across the region with costs generally lower in the northern states (Table 3A-11, Fig. 3A-13, 3A-14). Conversion costs contribute a significant portion of the costs for most regions at shorter time periods as the conversion costs occur at the outset of land management change (Table 3A-12). This will be especially true in areas with low crop or pasture yields such as Maine. The importance of opportunity costs increases over time and come become the dominating contributor to total costs. The total costs estimated are slightly higher than those found in a similar study in the southeastern state recently completed (Table 3A-13). Very low hay yields in Aroostook, ME and Warren, NY reported by NASS result in atypically low costs on pastureland for these counties. These two counties were removed from state and regional means to prevent a skewing of the results

Table 3A-11. Area weighted average total costs associated with conversion from cropland or pasture to forest land for each state.

	Cropland - Total Costs					
	$/acre			$/ha		
	10 yrs	20 yrs	40 yrs	10 yrs	20 yrs	40 yrs
Connecticut	2,017	2,985	4,081	4,983	7,376	10,086
Delaware	1,842	2,705	3,682	4,551	6,684	9,099
Maine	1,816	2,693	3,685	4,486	6,653	9,106
Maryland	2,627	3,473	4,431	6,492	8,583	10,950
Massachusetts	2,112	3,145	4,315	5,219	7,772	10,662
New Hampshire	2,047	3,074	4,237	5,057	7,595	10,469
New Jersey	2,297	2,935	3,658	5,676	7,253	9,038
New York	1,971	2,840	3,824	4,871	7,018	9,449
Pennsylvania	2,699	3,594	4,608	6,669	8,882	11,386
Rhode Island	1,803	2,627	3,560	4,456	6,492	8,798
Vermont	1,797	2,634	3,582	4,442	6,510	8,851
All States	2,280	3,150	4,135	5,634	7,784	10,218
Maximum	2,961	4,034	5,248	7,317	9,968	12,968
Minimum	1,020	1,365	1,757	2,520	3,374	4,341

	Pasture land - Total Costs					
	$/acre			$/ha		
	10 yrs	20 yrs	40 yrs	10 yrs	20 yrs	40 yrs
Connecticut	1,294	1,774	2,317	3,197	4,383	5,726
Delaware	1,462	2,067	2,753	3,612	5,109	6,804
Maine*	630	692	760	1,557	1,711	1,878
Maryland	2,382	3,063	3,834	5,886	7,569	9,475
Massachusetts	1,370	1,902	2,504	3,386	4,701	6,189
New Hampshire	1,115	1,508	1,952	2,755	3,726	4,825
New Jersey	NA	NA	NA	NA	NA	NA
New York*	1,093	1,370	1,682	2,702	3,384	4,157
Pennsylvania	2,200	2,759	3,391	5,437	6,817	8,379
Rhode Island	1,515	2,144	2,857	3,743	5,298	7,059
Vermont	1,075	1,249	1,565	2,656	3,087	3,868
All States	1,579	1,978	2,432	3,903	4,888	6,009
Maximum	2,961	4,034	5,248	7,170	9,721	12,610
Minimum	159	170	356	393	420	879

* Aroostook county, ME and Warren county, NY excluded from averages due to extremely low hay yields.

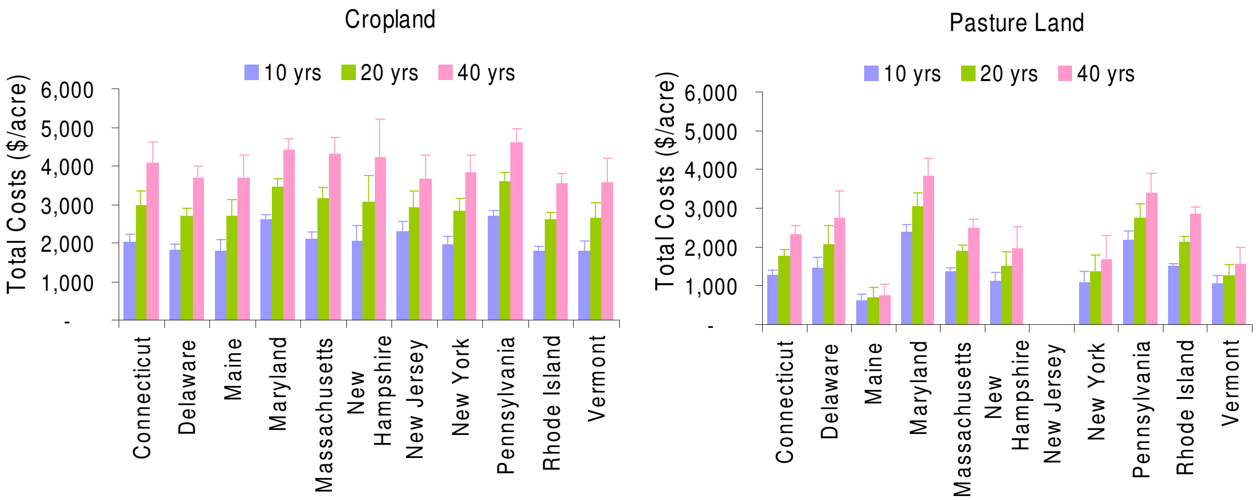


Figure 3A-13. Average total costs for each northeastern state for both cropland and pastureland.

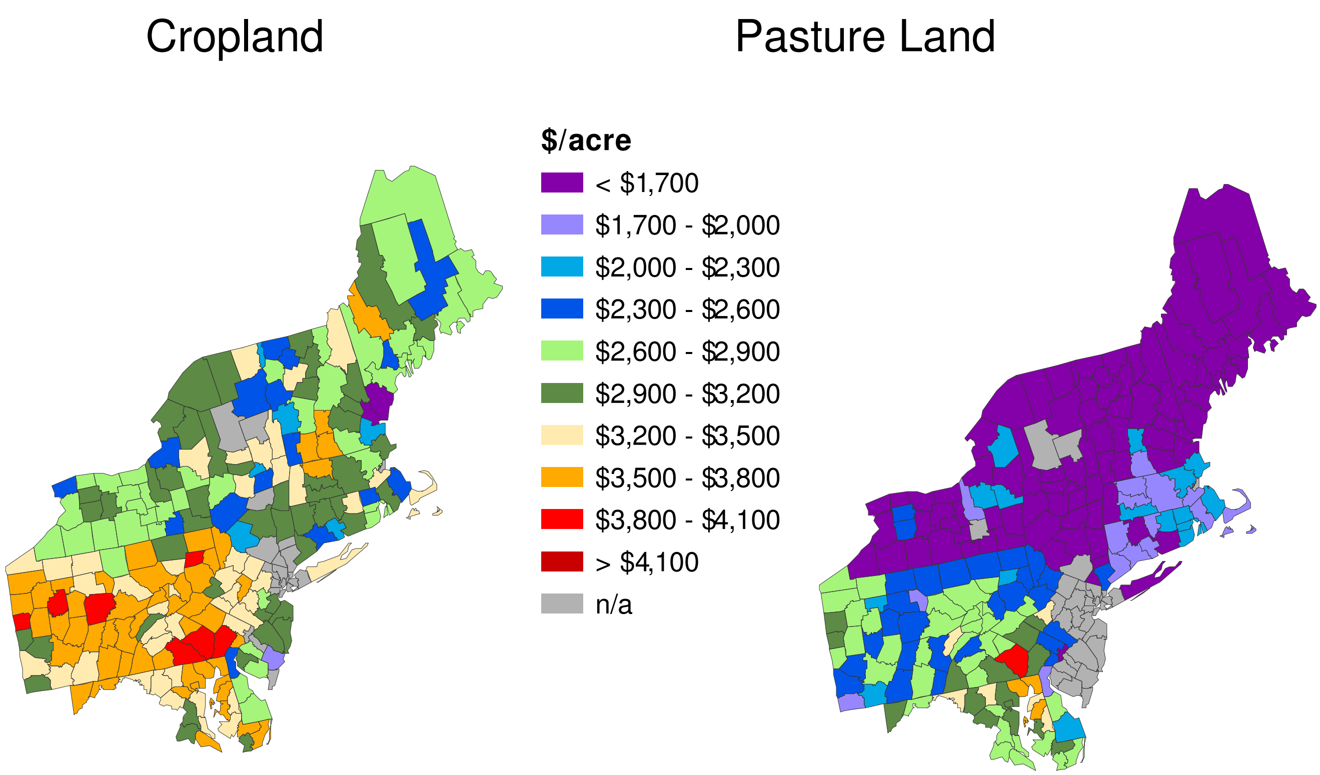


Figure 3A-14. Estimated total costs for afforestation of cropland and pasture land after 10 years, in $/acre.

Table 3A-12. Contribution to total costs of each component costs.

	10 year			20 year			40 year		
	Opportunity	Conversion	M+M	Opportunity	Conversion	M+M	Opportunity	Conversion	M+M
Cropland									
Connecticut	72%	26%	1%	81%	18%	1%	86%	13%	1%
Delaware	68%	31%	1%	78%	21%	1%	83%	16%	1%
Maine	71%	28%	1%	80%	19%	1%	85%	14%	1%
Maryland	47%	52%	1%	60%	40%	1%	68%	31%	0%
Massachusetts	74%	25%	1%	83%	16%	1%	87%	12%	0%
New Hampshire	72%	27%	1%	81%	18%	1%	86%	13%	1%
New Jersey	40%	59%	1%	52%	47%	1%	61%	38%	1%
New York	65%	64%	2%	76%	52%	2%	82%	43%	1%
Pennsylvania	47%	52%	1%	60%	39%	1%	68%	31%	0%
Rhode Island	64%	35%	1%	74%	24%	1%	81%	18%	1%
Vermont	71%	28%	1%	80%	19%	1%	85%	14%	1%
Mean	63%	39%	1%	73%	28%	1%	79%	22%	1%
Pastureland									
Connecticut	57%	41%	2%	69%	29%	1%	76%	22%	1%
Delaware	62%	37%	1%	73%	26%	1%	79%	19%	1%
Maine	17%	80%	3%	25%	71%	3%	32%	63%	3%
Maryland	42%	57%	1%	54%	45%	1%	63%	36%	1%
Massachusetts	61%	38%	2%	72%	27%	1%	78%	20%	1%
New Hampshire	51%	47%	2%	63%	35%	1%	71%	27%	1%
New Jersey	30%	69%	1%	42%	57%	1%	51%	48%	1%
New York	34%	64%	2%	46%	52%	2%	55%	43%	1%
Pennsylvania	34%	65%	1%	47%	52%	1%	56%	43%	1%
Rhode Island	64%	35%	1%	74%	24%	1%	81%	18%	1%
Vermont	43%	55%	2%	55%	42%	2%	64%	33%	1%
Mean	45%	53%	2%	56%	42%	1%	64%	34%	1%

Table 3A-13. Area weighted average total costs ($/acre) associated with conversion from cropland or pasture to forest land for each state in the south (Brown and Kadyszewski 2005).

	Cropland $/acre			Pasture Land $/acre		
	20 years	40 years	80 years	20 years	40 years	80 years
Alabama	$1,101	$1,492	$1,750	$671	$865	$992
Arkansas	$1,026	$1,383	$1,618	$675	$870	$999
Florida	$2,797	$3,962	$4,734	$746	$975	$1,125
Georgia	$1,620	$2,247	$2,662	$777	$1,019	$1,179
Louisiana	$2,567	$3,627	$4,330	$752	$983	$1,135
Mississippi	$1,503	$2,077	$2,456	$709	$920	$1,059
North Carolina	$1,075	$1,454	$1,704	$691	$895	$1,029
South Carolina	$864	$1,148	$1,333	$692	$896	$1,030
Tennessee	$1,092	$1,479	$1,734	$662	$854	$978
Mean	$1,558	$2,157	$2,554	$678	$876	$1,006

3A.6 Carbon accumulation through afforestation of existing dominant forest types

3A.6.1 Approach

The USDA-NRCS National Resource Inventory (NRI) database was used to determine which forest type was most likely to exist in each county if land were afforested. Carbon sequestration potential was estimated by developing growth potential curves using compiled USDA Forest Service FIA database. The FIA database contains the largest amount of data on forest biomass and growth, and the database encompasses the entire region. This information was then combined with the spatial database of available lands to estimate the amount of potential CO_2e sequestered per county. This analysis estimates the increase in live tree carbon stocks resulting from afforestation. Afforestation of lands would most likely lead to an increase in soil carbon levels; however this carbon pool is not included in the analysis. The emission savings associated with halting agricultural equipment usage is not incorporated nor are the emissions resulting from equipment usage in land preparation and monitoring the land over time.

3A.6.2 Forest type selection analysis

From the NRI data base, sample points per county, and associated expansion factors, that moved from non-forest to a forest type between the 1987 and 1997 database years were extracted and summed for each county. This resulted in an estimated area of land per county that moved from non-forest to a particular forest type. The forest type with the greatest increase in area in each county was then assigned to that county. Most of the region's newly developed forests were deciduous forest types (Figure 3A-15). Coniferous forests were only assigned to counties in the northern states.

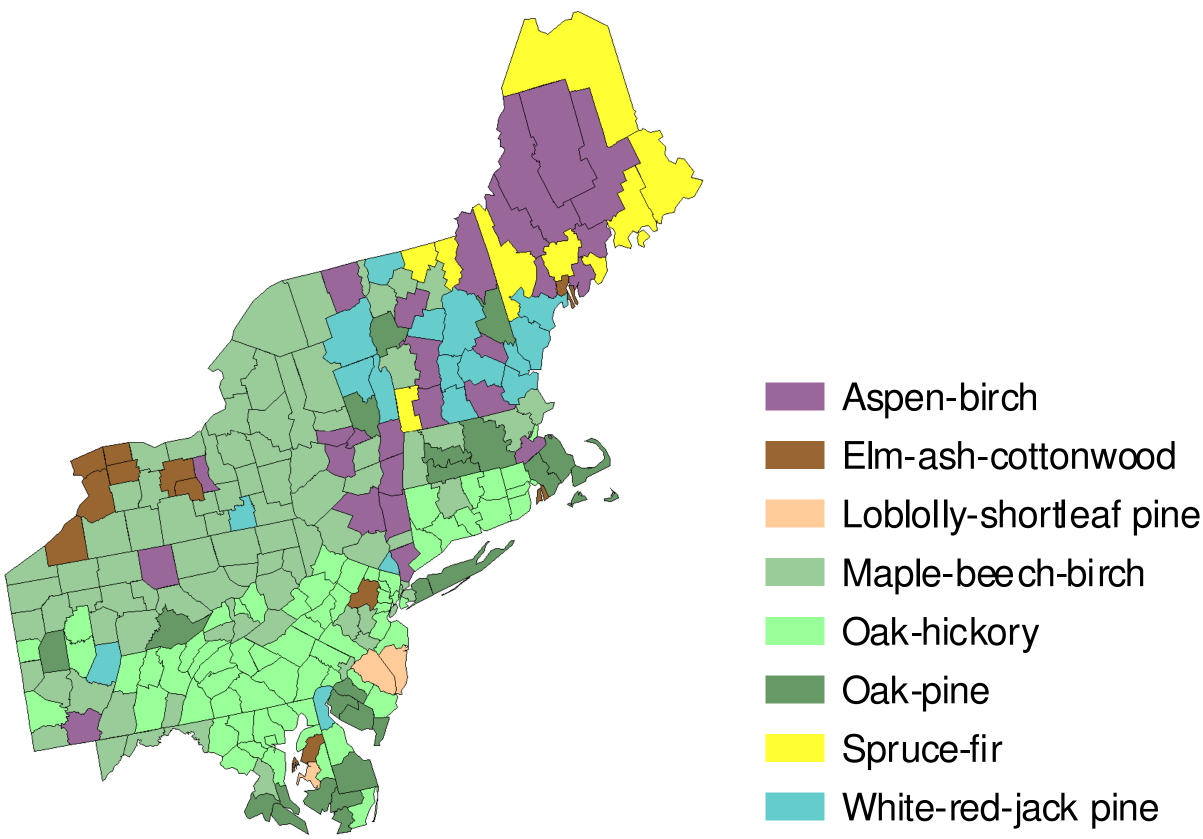


Figure 3A-15. Forest type assigned to afforestation activity of crop and pasture lands for each county.

3A.6.3 Modeling carbon accumulation potential

Using forest inventory data (FIA) data, volume yields were estimated for eight forest types and four site productivity classes (high, medium high, medium-low, and low) for the 11 states in the region. From these data, functions were developed to estimate potential growing stock volume per hectare of forest land. To form consistent estimates of forest biomass carbon accumulation potential throughout the analysis, these yield equations were also used in the analysis on the opportunities for carbon storage in existing forested land (Part 4 of this report). Volume to biomass expansion equations were then used to expand growing stock volume estimates to biomass carbon (Smith et al 2003, updated 2005). By using these equations, both above ground and belowground live tree biomass is estimated (Figure 3A-16).

The FIA data were also used to determine which site class to assign to a given county. The number of FIA plots of each site class in each county was extracted from the FIA database and a mean site class per county determined. Under this method, all counties were assigned to either the low or medium-low productivity classes; no mean county site classes fell into the higher classes. Using these rates of biomass accumulation equations, at 10 years, potential carbon sequestration averaged about 20 tons of carbon per hectare, or 30 tons CO_2e per acre (Table 3A-14). The carbon sequestration values obtained here by forest type are very similar to those reported in the recently released Voluntary Reporting of Greenhouse Gases (1605b) Program, Appendix A (1605b Appendix A).

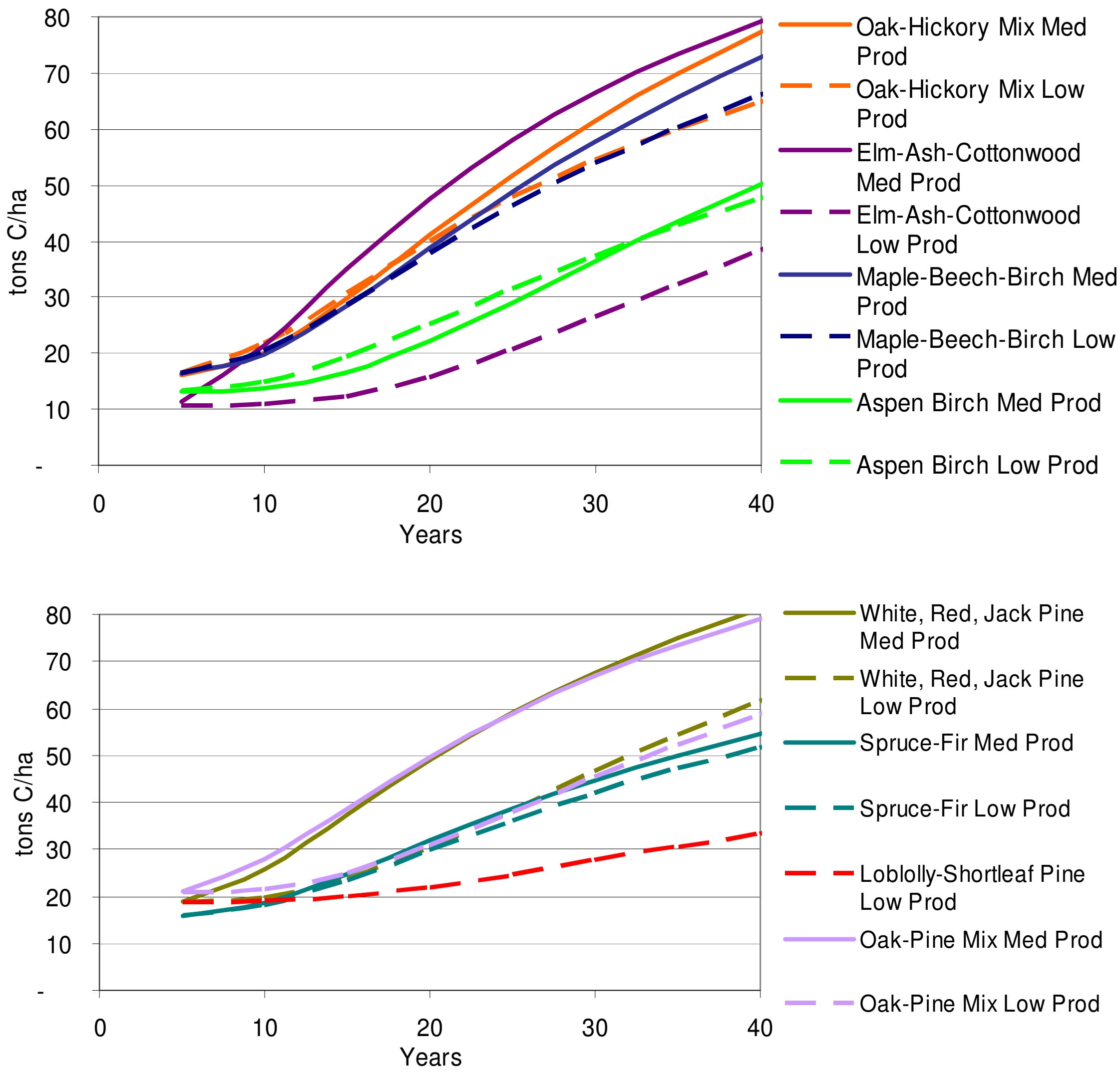


Figure 3A-16. Estimated carbon sequestration potential over time for medium and low productivity site classes.

Table 3A-14. Average potential sequestration through afforestation at the low and medium site classes.

	t C/ha		t CO_2/acre	
	average	range	average	range
10 years	20	11 - 28	31	15 - 42
20 years	38	15 - 50	57	23 - 74
40 years	68	33 - 81	100	50 - 120

3A.6.4 Estimated potential carbon sequestration in region

On average, there is the potential to sequester about 57 t CO_2e/acre through afforestation over 20 years (Table 3A-15, Figure 3A-16). This is somewhat smaller than the average carbon accumulation rate estimated for the southeastern states (Table 3A-16) using a similar analysis. The amount of potential carbon that could be sequestered through afforestation of croplands using existing forest types will be dependent on: the amount of land available in the county, the site quality, and the growth rate of the tree type (Table 3A-12, Figures 3A-17 to 3A-19). Counties with high site quality and assigned a forest type with higher productivity will be able to sequester greater levels of carbon within a specific time period. If all available land was afforested, after 10 years over 600 million tons of CO_2e could be sequestered in growing trees throughout the region (Table 3A-17). That estimate climbs to almost 2.2 billion tons of CO_2e at 40 years. The amount of land needed to sequester a given amount of CO_2e will vary depending on where in the region, and the time interval but on average, around 500 acres would need to be afforested to sequester 50,000 tons of CO_2e over 40 years (Table 3A-18).

Table 3A-15. County weighted mean estimated potential CO_2e sequestration per area (t CO_2e/acre) through afforestation in each state.

	10 years	20 years	40 years
Connecticut	30	60	109
Delaware	37	69	117
Maine	27	46	81
Maryland	30	52	89
Massachusetts	36	65	112
New Hampshire	33	58	104
New Jersey	31	53	92
New York	29	56	102
Pennsylvania	31	60	109
Rhode Island	27	52	100
Vermont	30	53	95
All States	31	57	100

Table 3A-16. Estimated CO_2e sequestration (t CO_2e/acre) in the southeastern states (Brown and Kadyszewski 2005).

	20 years	40 years	80 years
Alabama	74	133	162
Arkansas	61	122	161
Florida	82	139	163
Georgia	82	138	160
Louisiana	70	127	158
Mississippi	77	137	166
North Carolina	67	123	153
South Carolina	81	138	161
Tennessee	57	123	172
All States	73	132	162

Table 3A-17. Estimated total potential t CO_2e sequestered if all cropland and pastureland areas were afforested.

	Cropland			
	Acres	estimated tons of sequestered CO_2e		
		10 years	20 years	40 years
Connecticut	110,927	3,369,997	6,619,143	12,051,135
Delaware	503,010	18,564,761	34,733,047	58,781,317
Maine	213,690	5,742,619	9,828,373	17,316,277
Maryland	1,770,317	53,849,262	92,204,385	158,259,850
Massachusetts	222,538	7,924,021	14,551,972	24,885,906
New Hampshire	15,353	499,222	895,675	1,591,073
New Jersey	83,586	2,627,406	4,456,314	7,689,456
New York	1,747,942	50,529,088	98,061,075	179,019,220
Pennsylvania	1,438,822	44,057,019	85,853,936	156,202,690
Rhode Island	25,293	684,641	1,324,787	2,531,916
Vermont	572,485	17,165,392	30,324,131	54,615,671
Total	6,703,964	205,013,428	378,852,837	672,944,509

	Pasture Land			
	Acres	estimated tons of sequestered CO_2e		
		10 years	20 years	40 years
Connecticut	270,785	8,281,842	16,192,350	29,184,351
Delaware	3,665	139,097	259,109	431,761
Maine	998,072	26,514,256	46,133,066	85,200,448
Maryland	219,866	6,884,316	12,351,090	20,893,212
Massachusetts	91,464	3,247,046	5,949,025	10,193,065
New Hampshire	220,863	6,836,675	12,019,507	21,756,878
New Jersey	NA	NA	NA	NA
New York	6,021,915	174,070,178	339,543,685	624,781,857
Pennsylvania	6,527,641	199,379,007	386,738,699	702,070,126
Rhode Island	15,009	412,773	799,013	1,512,866
Vermont	308,092	9,598,080	16,617,681	29,796,277
Total	14,677,405	435,364,309	836,605,275	1,525,824,681

Table 3A-18. Estimated area needed, in acres, to sequester specified levels of CO_2e through afforestation.

Sequestered tons CO_2e	Acres		
	10 years	20 years	40 years
10,000 t	327	177	100
50,000 t	1,635	885	498
100,000 t	3,270	1,770	996
1 million t	32,700	17,695	9,962

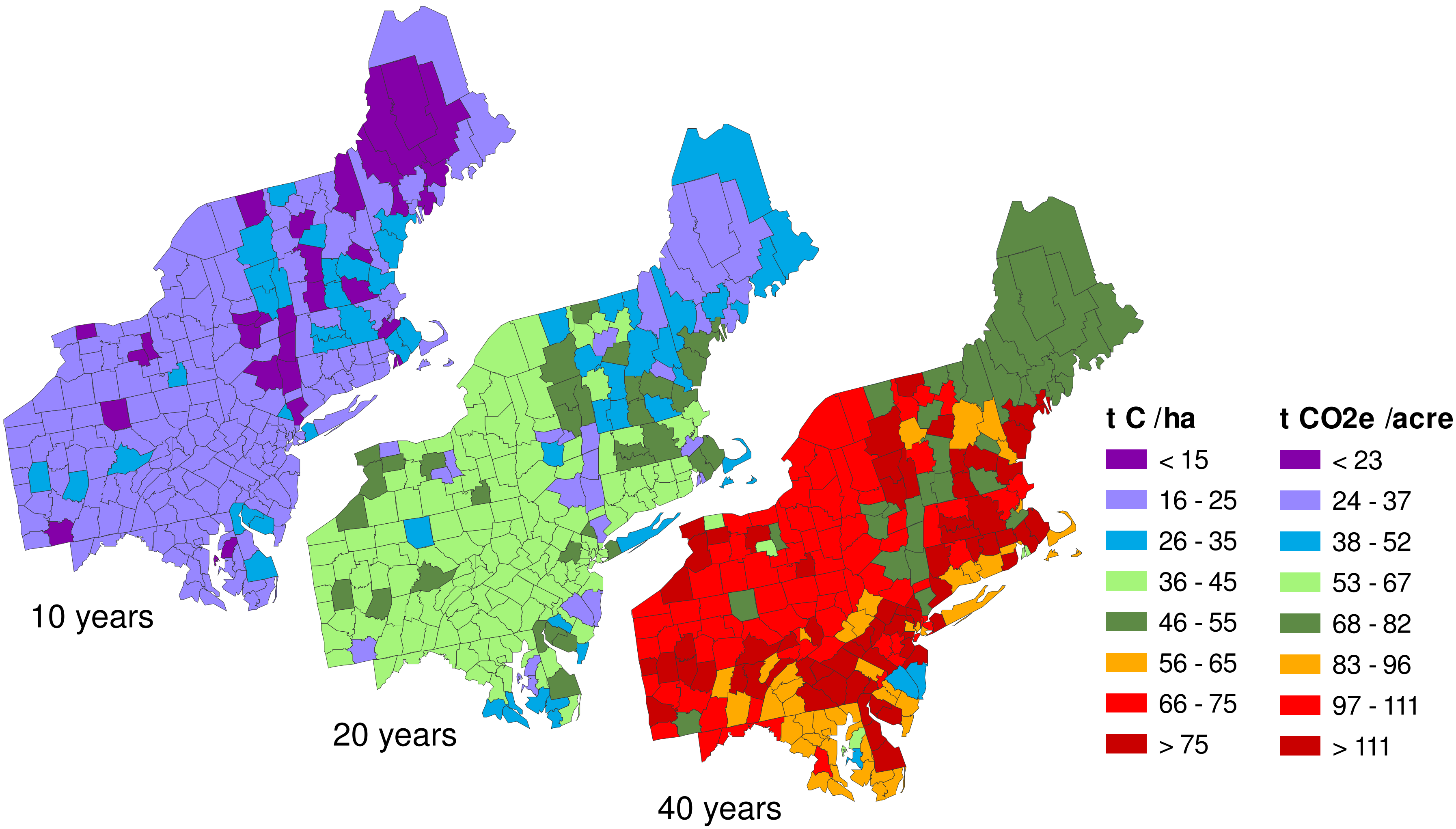


Figure 3A-17. **Estimated CO_2e sequestered per area for each county after 10, 20, and 40 years.**

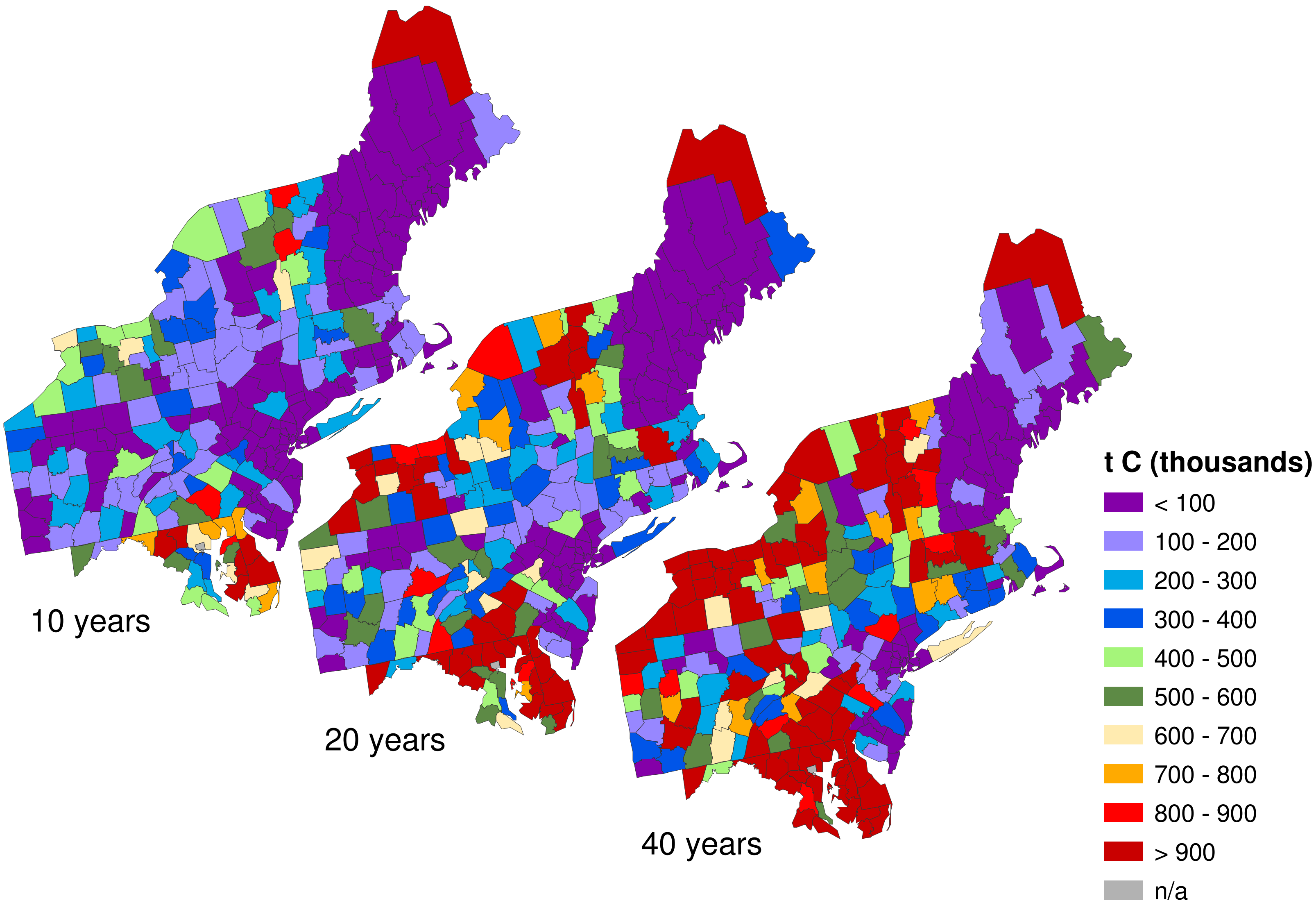


Figure 3A-18. Estimated total quantity of carbon sequestered, in thousands of tons, on croplands for each county.

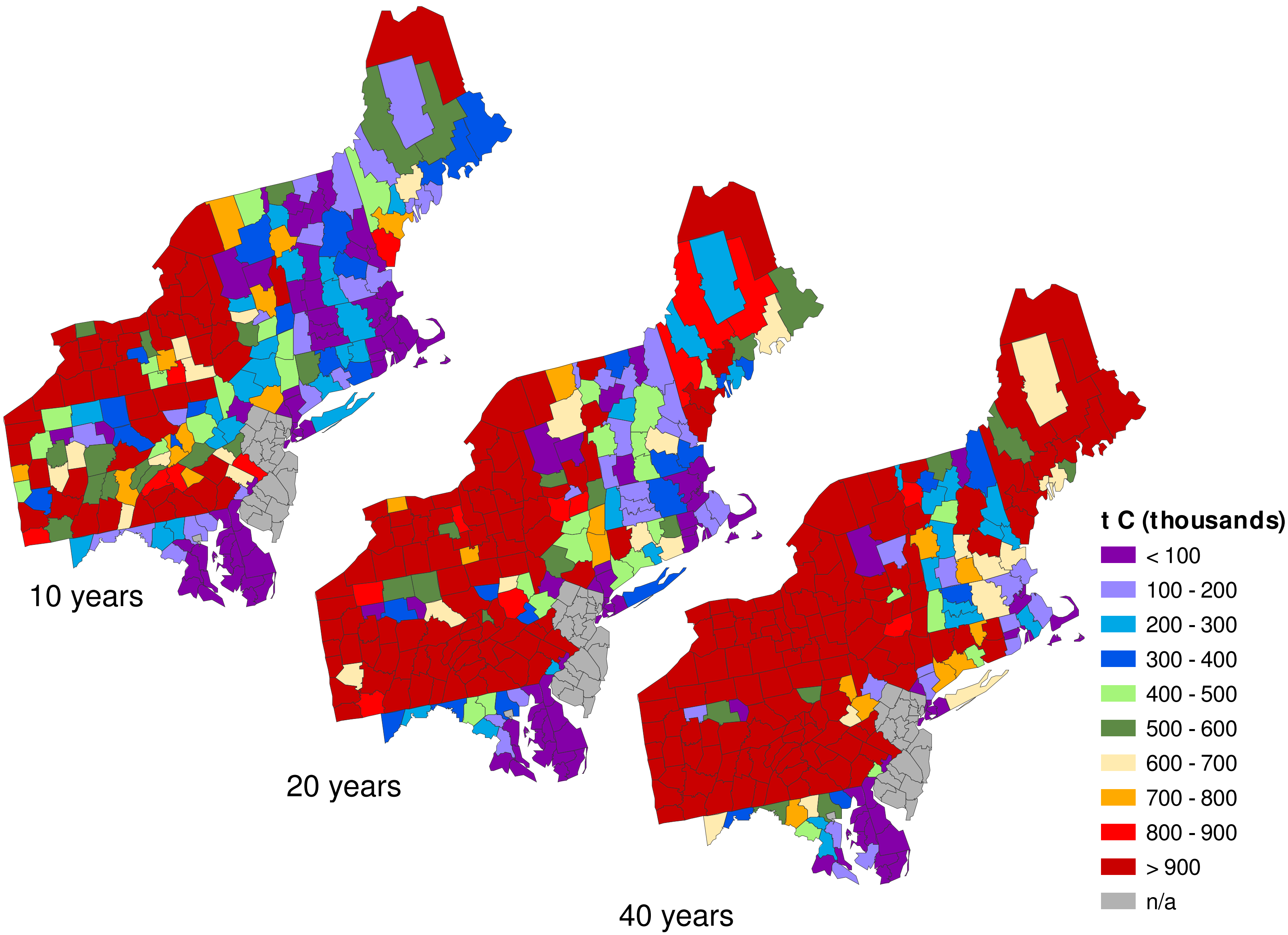


Figure 3A-19. Estimated total quantity of carbon sequestered, in thousands of tons, on pasture lands for each county

3A.7 Marginal Costs and Supply of Carbon

3A.7.1 Approach

The final stage in the analysis is to combine the total costs associated with ceasing agricultural activities and afforesting with the projected sequestered carbon from this land use action. The resulting marginal cost per ton CO_2e for this land management practice can then be easily compared with other mitigation options.

Discounting is an essential economic concept for making accurate comparisons today of options and alternatives that happen in the future. Throughout this study, present value techniques are used to discount future flows of costs and carbon to generate estimates of the marginal cost of carbon sequestration. Present value techniques integrate the concept of the time value of money into economic decisions that occur over time.

In this analysis, it is assumed that companies only get credit for the carbon in the year new carbon is created. Thus, the present value of the benefits derived from sequestering carbon over time (estimated as the product of quantity and price) is compared to the present value of the costs to sequester the carbon. This is illustrated by the following example. Suppose a company considers investing in a project that has a stream of costs over time t, C_t (from section 3A.4), a stream of annual carbon sequestration (or losses), S_t (from section 3A.3), and a stream of the benefits of sequestering a ton of carbon in each year, P^c_t (Eq. 1a). The benefits value is related to the price of carbon that would evolve in a carbon market, thus it represents the marginal costs of abating carbon in the next best alternative for the company, i.e. its total cost for sequestering carbon. With a discount rate equal to r, a company would choose to invest in projects when the following condition holds (where r is the discount rate), that is when the price of carbon is such that the costs are less than the carbon benefits:

$$\int_1^X C_t e^{-rt} dt < \int_1^X P_t^c S_t e^{-rt} dt \qquad \text{(Eq. 1a)}$$

Assuming that the price of carbon rises at a rate of "*g*" over time, this equation becomes (where P^c_0 is the initial benefit):

$$\int_1^X C_t e^{-rt} dt < \int_1^X P_0^c e^{gt} S_t e^{-rt} dt \qquad \text{(Eq. 1b)}$$

that simplifies into

$$\int_1^X C_t e^{-rt} dt < \int_1^X P_0^c S_t e^{(g-r)t} dt \qquad \text{(Eq. 1c)}$$

From the perspective of a company considering investing in carbon sequestration in forests, it is important to include discounting in the analysis. Further, companies need to carefully consider both the choice of discount rates for carbon flows, and the time length of the project. Considering the discount rates for carbon flows, the correct choice of discount rate will depend on assumptions about the future growth of the total cost of carbon sequestration. If one assumes that carbon prices remain constant (*g=0*) over time, then carbon flows should be discounted at financial rates of discounting (i.e., 6% in this case). And, the marginal cost per ton (P_c) for a given project can be estimated by re-arranging and solving Eq 1c:

$$\frac{\int_1^X C_t e^{-rt} dt}{\int_1^X S_t e^{(g-r)t} dt} < P_0^c \qquad \text{(Eq. 2)}$$

As can be seen in equation (2), when *g* is 0, carbon flows can be discounted at financial discount rates and the costs per ton can be compared to the current total costs of carbon sequestration. All analyses presented here use a financial discount rate of 6% and assume no growth in the price of carbon (*g*=0)

3A.7.2 Results

Prices per ton of CO_2e will vary dependent on both the costs associated with conversion and the potential carbon sequestration capacity. Prices ranged from a minimum of \$39/ton CO_2e to a maximum of \$230/ton CO_2e for a 10 year period in cropland and range from \$15-\$237/ton CO_2e for pasture land (Table 3A-19). Areas with low cost per ton CO_2e are areas with both low total costs of land use change and rapid carbon sequestration rates. Due to higher opportunity and conversion costs, the southerly states in this northeast region tend to have higher costs per ton of CO_2e (Figures 3A-20, 3A-21). For all counties, pasture areas have lower costs per ton CO_2e because of the lower opportunity costs associated with pasture land. Very low hay yields in Aroostook, ME and Warren, NY reported by NASS result in atypically small \$/ton CO_2e estimates for these counties. Therefore, these two counties were removed from state and regional means to prevent a skewing of the results. In comparison to results from recent study for the southeastern United States (Brown and Kadyszewski 2005), prices in the northeastern United States are greater (Table 3A-20). Again, this is due to the lower growth rates and higher costs found in the northeast region.

Table 3A-19. Area-weighted mean estimated \$/ton CO_2e for each state for cropland and pasture land.

	Cropland				Pasture land			
	Area (acres)	mean \$/ton CO_2e			Area (acres)	mean \$/ton CO_2e		
		10 years	20 years	40 years		10 years	20 years	40 years
Connecticut	110,927	90	87	94	270,785	58	52	53
Delaware	503,010	69	68	75	3,665	54	51	56
Maine*	213,690	93	100	110	998,072	35	27	24
Maryland	1,770,317	122	118	122	219,866	104	93	95
Massachusetts	222,538	84	85	94	91,464	54	51	54
New Hampshire	15,353	90	96	104	220,863	52	50	50
New Jersey	83,586	101	97	100	NA			
New York*	1,747,942	97	95	99	6,021,915	53	45	42
Pennsylvania	1,438,822	121	105	106	6,527,641	99	81	79
Rhode Island	25,293	98	100	102	15,009	80	78	79
Vermont	572,485	85	89	96	308,092	48	40	40
All States	6,703,964	105	101	105	14,677,370	73	61	58
Minimum		39	36	38		15	12	10
Maximum		230	248	227		237	257	236

* Aroostook county, ME and Warren county, NY excluded from averages due to extremely low hay yields.

Table 3A-20. Estimated marginal cost of sequestering carbon (\$/ton CO_2e) by afforesting crop and pasture land in each of the south and southeastern states (revised values from Brown and Kadyszewski 2005).

	Cropland		Grazing Land	
	20 years	40 years	20 years	40 years
Alabama	23	21	16	10
Arkansas	52	39	20	11
Florida	53	49	14	10
Georgia	31	33	13	10
Louisiana	79	62	17	11
Mississippi	39	31	14	10
North Carolina	26	24	14	10
South Carolina	15	15	11	9
Tennessee	25	20	14	8
Mean	41	34	16	10
Maximum	382	243	69	33
Minimum	4	3	7	6

The maximum amount of potentially sequestered CO_2e and the maximum area of land available for economically attractive afforestation can be calculated for a certain price per ton CO_2e by summing the estimated potential CO_2e sequestered and the area available in the counties with prices at or below this price level (Figures 3A-22, 3A-23). For longer time periods, the total maximum amount of CO_2e sequestered increases at all price points as trees accumulate carbon through time.

Several counties in Maine and New York have both low marginal costs for afforestation and a large potential quantity of sequestered CO_2e via afforestation (Figure 3A-24). This large CO_2e quantity is due to an average carbon accumulation estimate combined with a large area of agricultural land in the county. The low marginal costs in these counties are predominately the result of low USDA-NASS reported hay yields for those counties. Although biomass accumulation was not modeled for each county separately, the USFS FIA reported biomass estimates for the counties with low marginal costs were examined and were found to be in the range of the estimates produced by the biomass accumulation equations developed. Therefore, the low hay yields may indicate lower site quality of current pasture land than existing forested land in that county or suboptimal current land management.

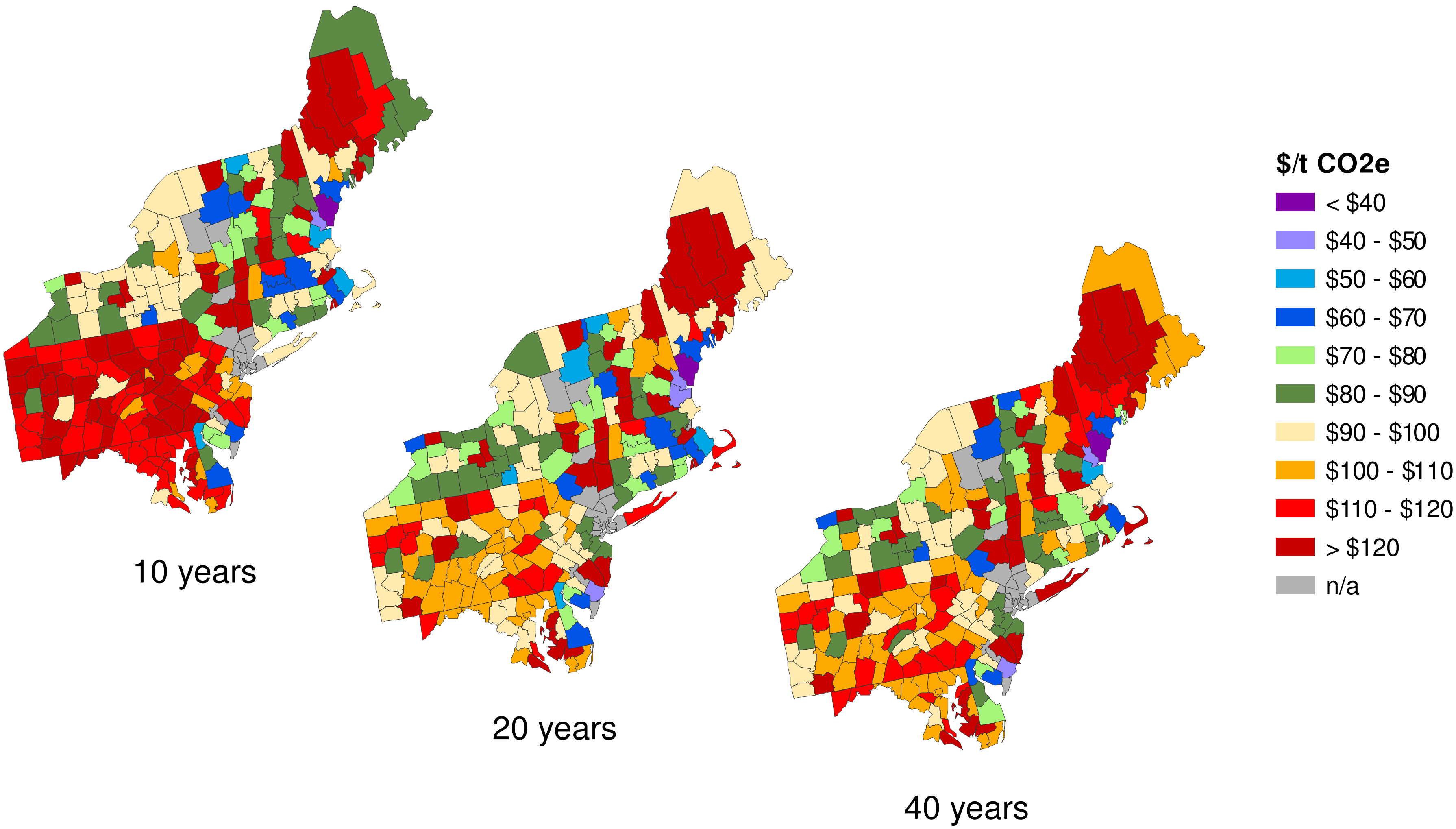


Figure 3A-20. Marginal costs of potential carbon supply for crop land areas

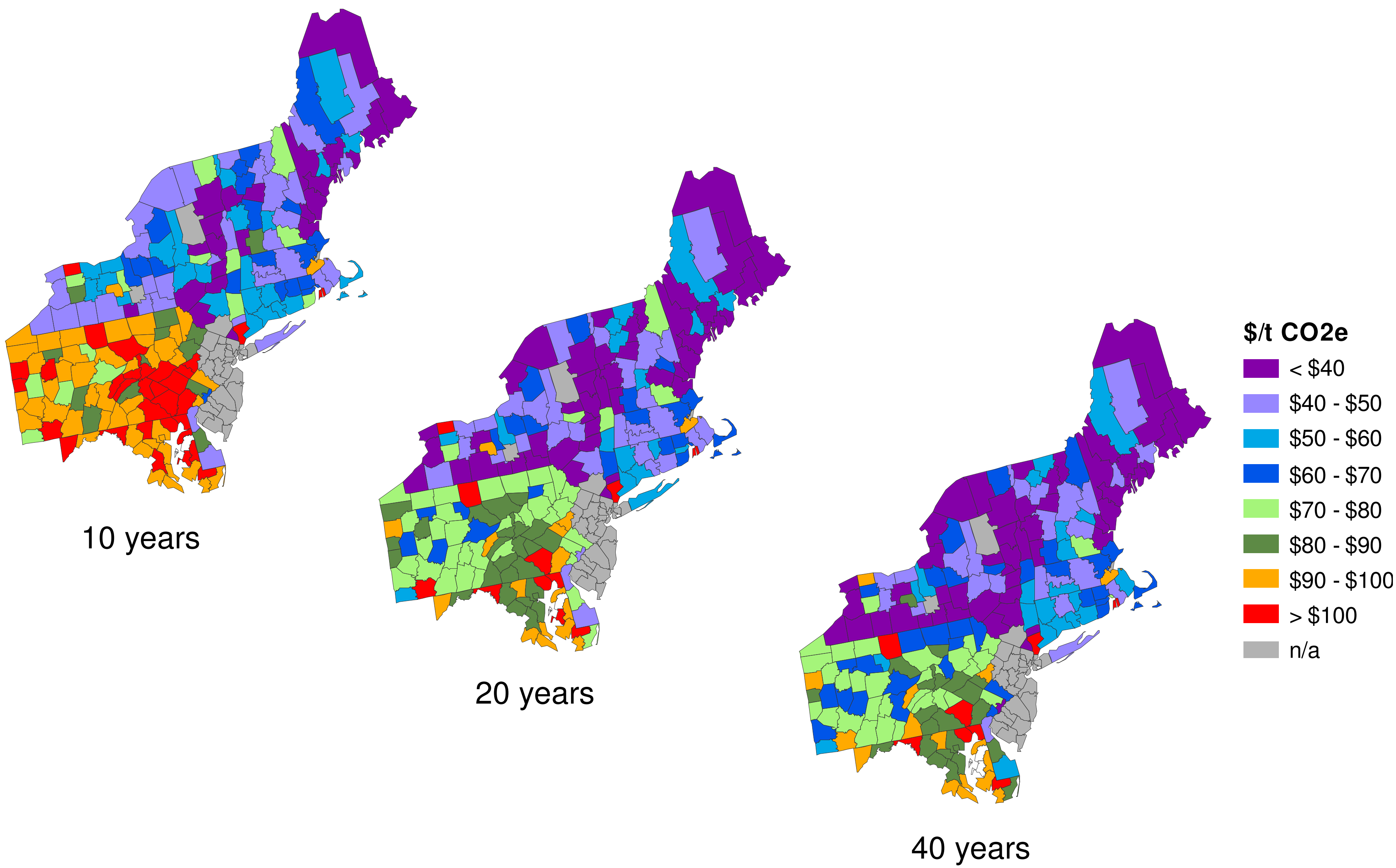


Figure 3A-21. Marginal costs of potential carbon supply for pasture land areas.

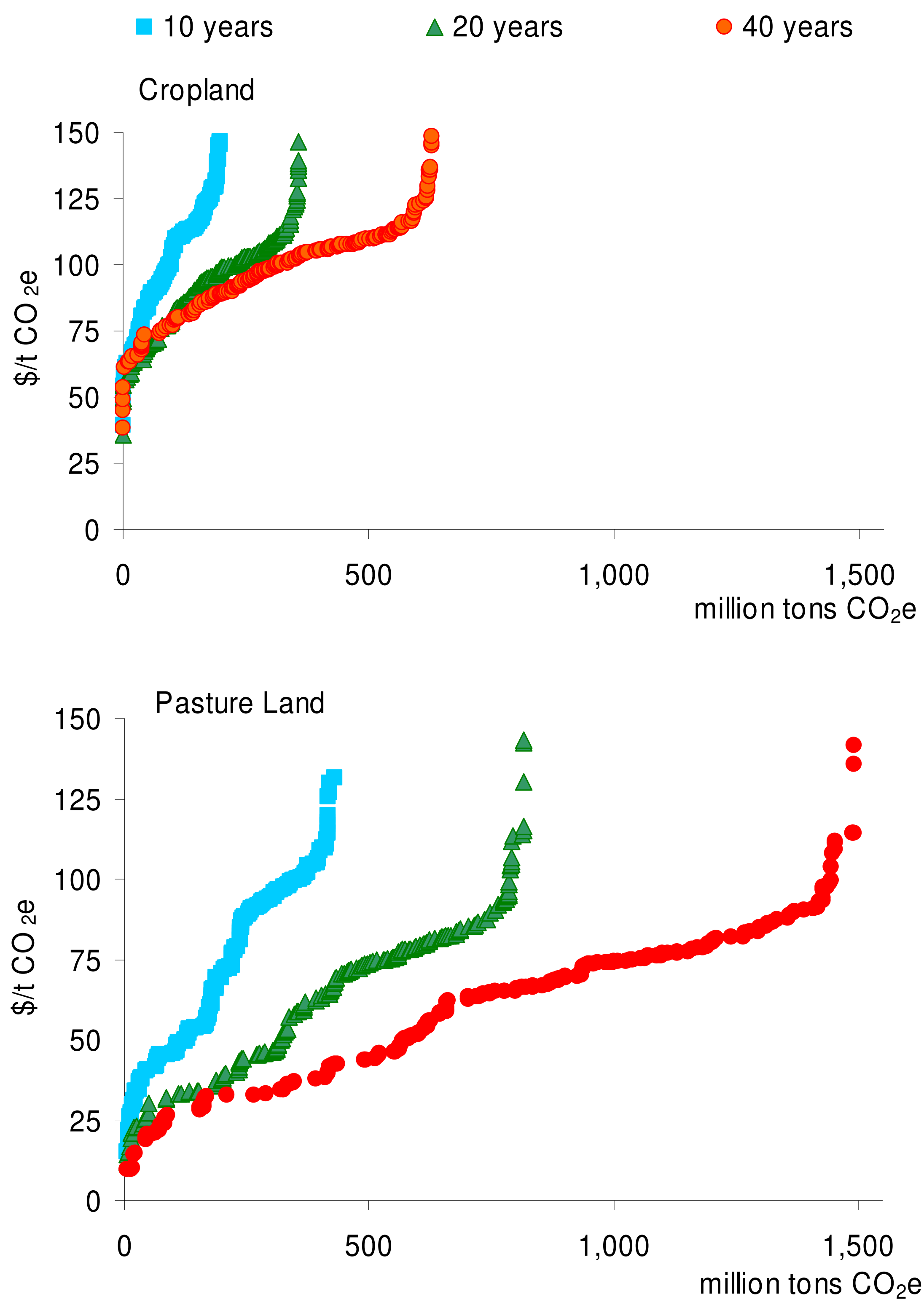


Figure 3A-22. Estimated carbon supply at various prices per ton of CO_2e for various years, for cropland and pasture land. Each point represents one county.

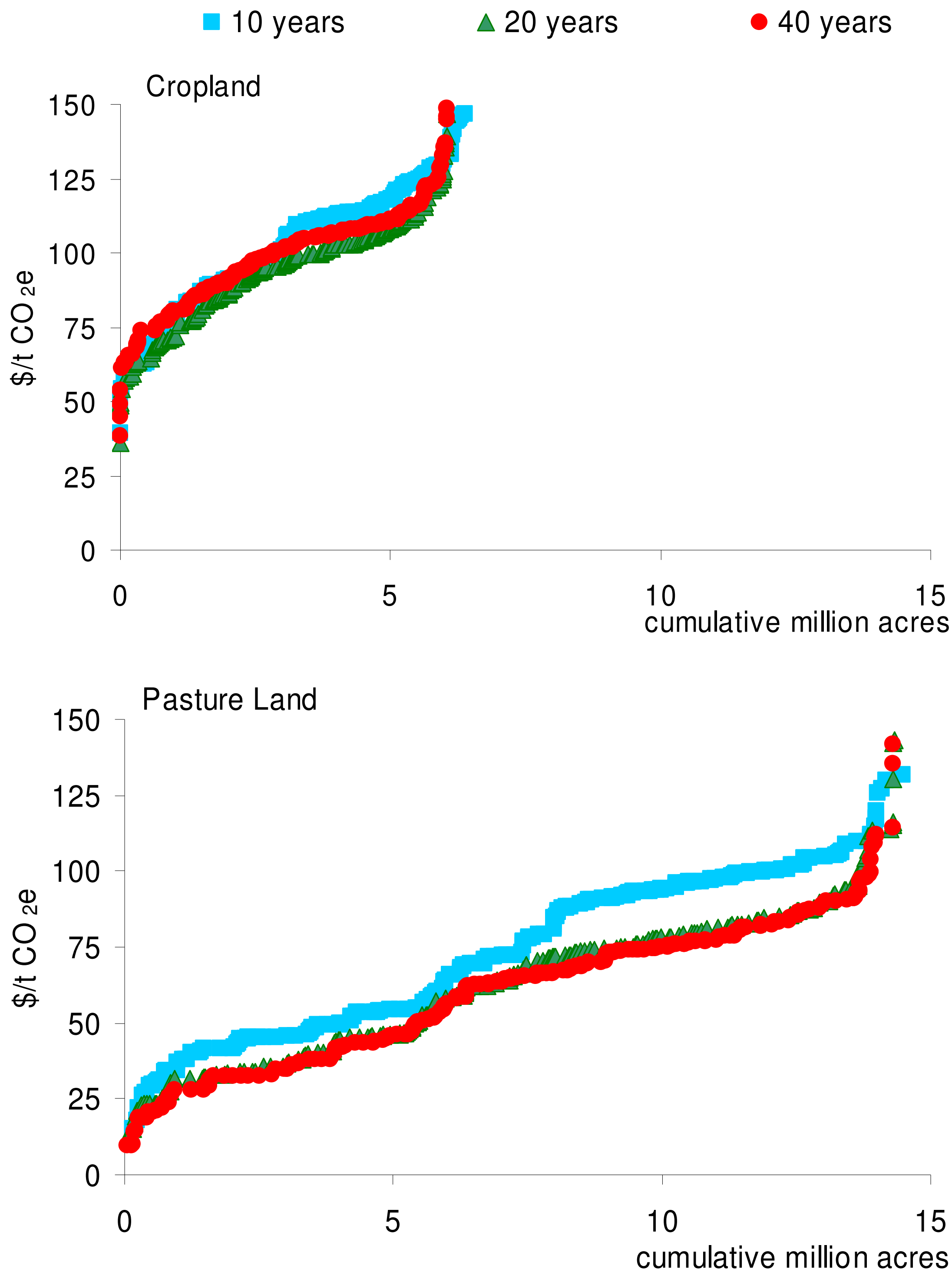


Figure 3A-23. **Estimated area of land available at various prices per ton of CO_2e for various years, for cropland and pasture land.**

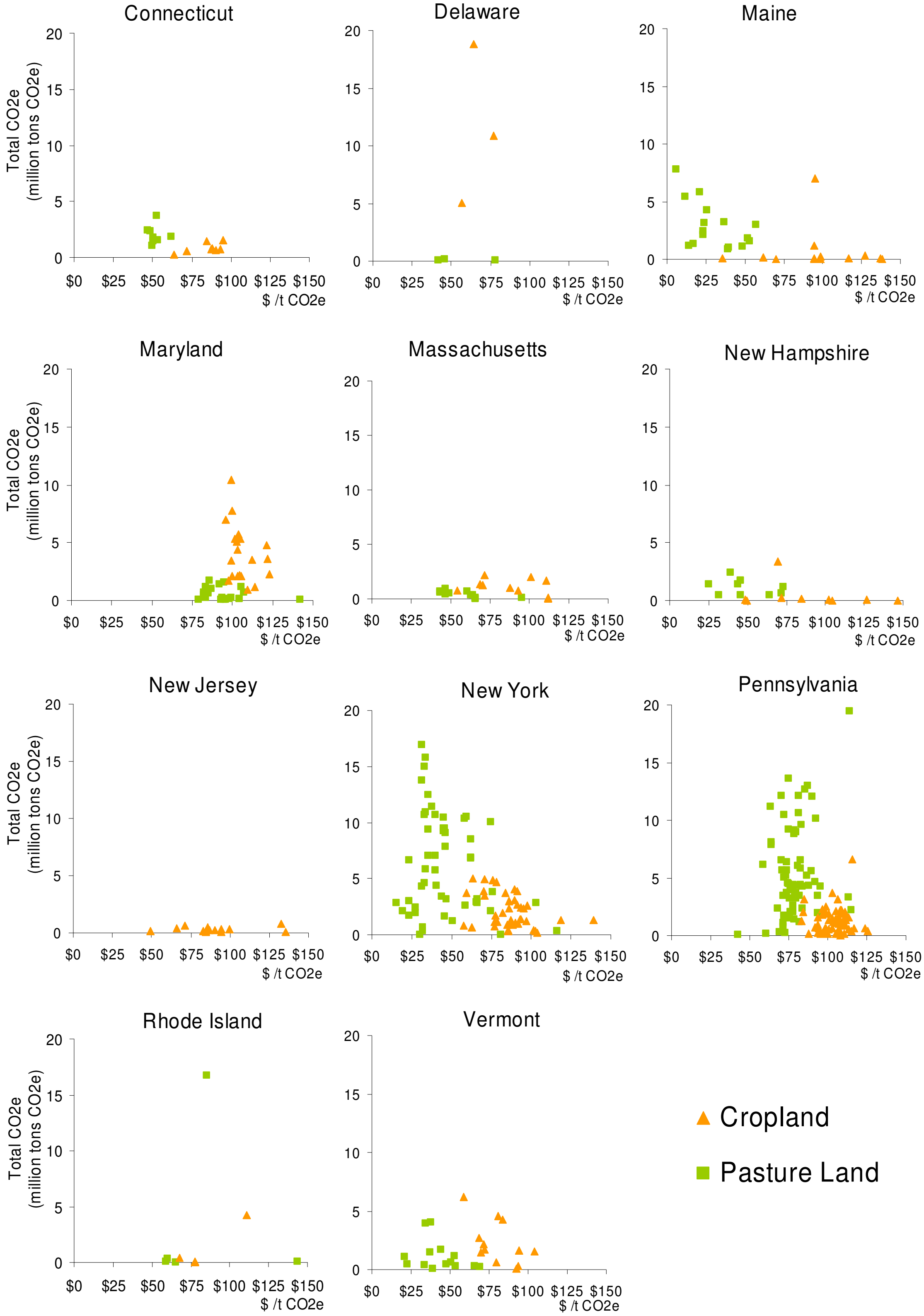


Figure 3A-24. Comparison of marginal costs and total quantity available in each state for 20 year period.

At prices below $50/ton CO_2e, very little cropland is available for afforestation-based sequestration (Table 3A-21 and 3A-22, Figure 3A-24). It would become economically attractive to sequester carbon through afforestation of more than a million acres of pasture land if prices reached $40/t CO_2e. Counties in Maine, Vermont, and New York offer the best opportunities, with low marginal costs and large areas of pastureland available for afforestation (Figure 3A-25).

Table 3A-21. Estimated total amount of CO_2e that could be sequestered by afforestation at various price points.

	Estimated total potential tons CO_2e					
	Cropland			Pasture land		
	10 years	20 years	40 years	10 years	20 years	40 years
$7/t CO_2e	0	0	0	141,000	8 million	13.8 millon
$10/t CO_2e	0	0	0	4.7 million	8 million	28.3 million
$20/t CO_2e	0	0	0	7.5 million	18.9 million	59 million
$40/t CO_2e	61,000	116,000	191,800	36.8 million	214 million	430 million
$50/t CO_2e	103,000	344,000	487,000	124 million	324 million	583 million

Table 3A-22. Estimated area economically attractive for afforestation at various price points.

	Estimated potential available area (acres)					
	Cropland			Pasture land		
	10 years	20 years	40 years	10 years	20 years	40 years
$7/t CO_2e	0	0	0	3,600	170,000	170,000
$10/t CO_2e	0	0	0	3,600	170,000	294,000
$20/t CO_2e	0	0	0	244,000	374,000	582,000
$40/t CO_2e	1,600	1,600	1,600	1.28 million	3.6 million	4 million
$50/t CO_2e	2,800	5,000	4,700	4 million	5.5 million	5.6 million

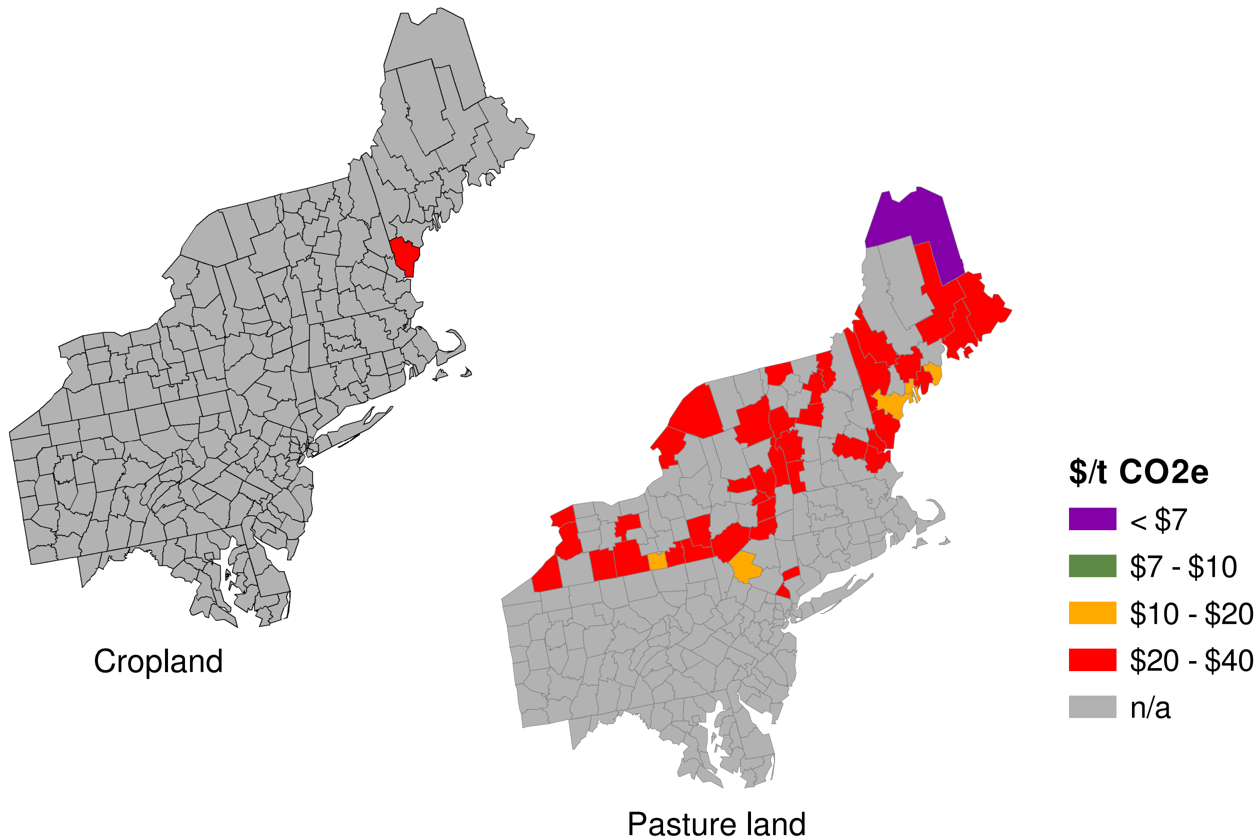


Figure 3A-25. Counties where afforestation is more economically attractive at lower prices of CO_2e for a 20 year period.

3A.7.3 Future Work: Uncertainty Analysis with Stochastic Prices and Yields

The analysis in this report has been conducted using historical data and best scientific estimates for the mean value of relevant input variables. Although using the means of such variables provides the single best estimate of results, it is important to realize that there can be significant variability in the realization of yields and prices across different years. An analysis using stochastic prices and yields has a much larger computational burden, but can provide information that a deterministic analysis cannot. This section provides an example of how such variability in input parameters can be quantified and used to provide results, as $/t CO_2e, that are presented as probability distributions.

There are many factors in this analysis that contain variability. However, the variables that have the greatest impact on the results are crop prices, crop yields, and C accumulation rates. Prices and yields are the primary drivers of the opportunity cost of foregoing agricultural production to produce trees on crop and pasture land. As shown in Table 3A-12 above, the opportunity costs are by far the single largest segment of the total costs of afforestation on agricultural land. The percentage of total costs that are from foregoing agricultural production (i.e. opportunity costs) increase with the length of the C project and account for up to 86% of the total costs.

An example is presented for the state of Delaware, of how a Monte Carlo type simulation can be used to account for the uncertainty in the results that are caused by the variability in crop prices and yields and C sequestration rates. The software package @Risk was used to produce individual realizations for each of these variables according to the most appropriate, pre-specified distributions. The distributions are each sampled 1,000 times (i.e. Monte Carlo) and each time the worksheet is recalculated and the results are recorded. When the 1,000 iterations are complete, a distribution of results is created. The set of values that result each have a probability associated with them. These values are the predicted mean level for the variable and the associated probability indicates the likelihood that that mean value will be at or below the level shown.

As described below, crop prices and yields are highly correlated (inversely), as are the yields of different crops (directly) for any given year; empirically-estimated correlation coefficients are specified in @Risk. The outputs of concern from this stochastic analysis are the probability distributions for the $/ton CO_2e that can be produced on crop and pasture land for each county and various time periods. Each of the variables in the stochastic analysis is assumed to be distributed normally. Therefore, the distributions can be completely specified with a mean and a standard deviation.

Crop Prices

The mean value for the price of each crop analyzed (corn, soybeans, and hay) is taken as the average of the annual price projections, compiled by FAPRI at the University of Missouri, through the year 2014. This mean value has been used as a deterministic crop price throughout this report. The standard deviations for each price distribution were calculated from historical data compiled by the USDA National Agricultural Statistics Service (NASS) (Figs. 3A-26-28).

The probability density function (PDF) for the prices of corn, soybeans, and hay present the mean and the distribution around that mean. For example, the mean value for the price of corn is $2.29/bu and 90% of the values for corn price will fall between $1.53 and $2.92, with increasing frequency clustered around the mean (Figure 3A-26). The mean value for the price of soybeans is $5.28/bu (Figure 3A-27) and for hay the mean price is $92.22/ton. The Monte Carlo analysis performed in this section draws 1,000 values from each of these price distributions according to the PDFs shown (i.e. the highest frequency of values are clustered around the mean). An identical process is used to reflect variability in crop yields and carbon accumulation, as discussed in the following section.

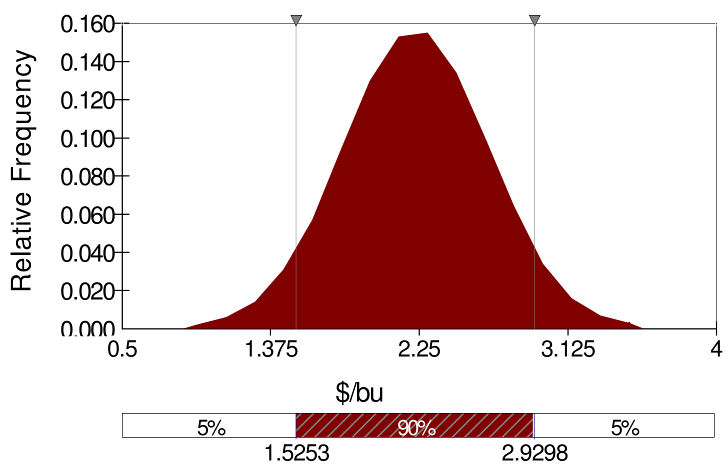


Figure 3A-26. Probability (Relative Frequency) Distribution of Corn Price ($/bu). The bar below the x-axis indicates the values within the 90% confidence interval.

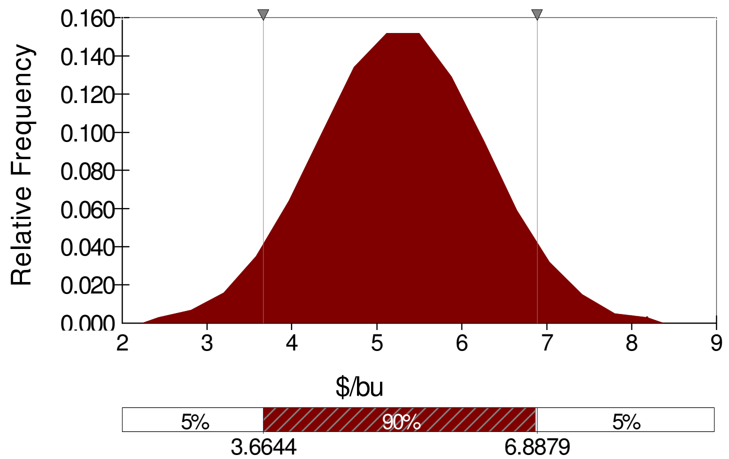


Figure 3A-27. Probability (Relative Frequency) Distribution of Soybean Price ($/bu). The bar below the x-axis indicates the values within the 90% confidence interval.

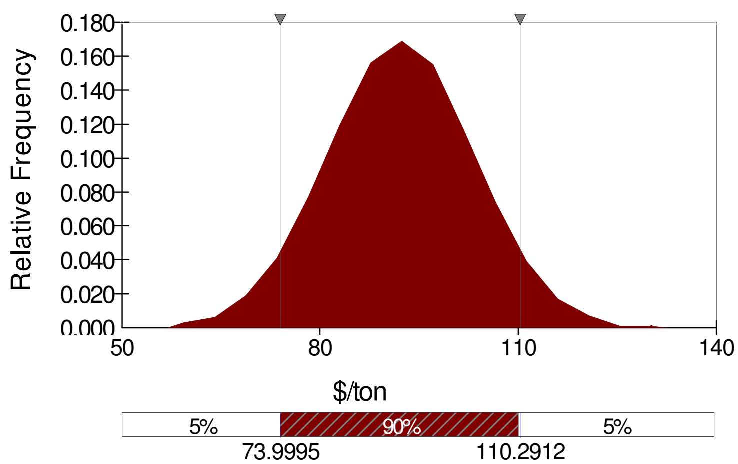


Figure 3A-28. Probability (Relative Frequency) Distribution of Hay Price ($/ton). The bar below the x-axis indicates the values within the 90% confidence interval.

Crop Yields
A single yield index distribution has been created that is applied to each of the three crops in this analysis. This single yield index approach was chosen, rather than having individual yield distributions for each crop, for two reasons. First, there is a very high correlation among the yields for each crop in any given year. This is because the primary factor for the yield of all crops is the weather. Second, having individual yield distributions specified in the model for each crop adds to the complexity and computational burden of the analysis.

The distribution of the crop yield index has a mean of 1.0 and a standard deviation of 0.3 (Fig. 3A-29). The distribution is truncated so it will not fall below 0 (as a negative yield index is meaningless) and will not go above 1.98 (because 200% of mean yields is highly improbable). Each time that a yield index number is drawn from this distribution it is multiplied by the historical, county-specific, average crop yield figure used in the deterministic analysis described throughout this report. Ninety percent of the time the yield index will be between 51% and 149% of the average value, with increasing probability of the draws being clustered around 100% (the historical average for the county) (Fig. 3A-29).

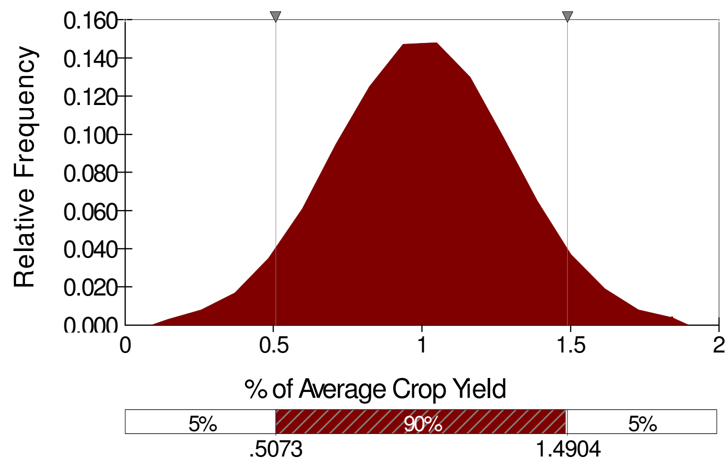


Figure 3A-29. Probability Distribution of Crop Yield Index.

Correlation Coefficients
Three correlation coefficients are specified to govern the relationship that exists between the yield index and the price of each of the three crops (Table 3A-23). The inverse correlations between price and yields vary from -0.41 for hay to -0.71 for corn. These correlation coefficients were empirically estimated from historical data compiled by USDA-NASS for the years 1980-2005. The inverse relationship is consistent with economic theory and the laws of supply and demand. The absolute values are also consistent with agronomic expectations of the ability for weather conditions to affect corn production much more than hay production. Hence, a given move in the yield index produces a greater effect on corn prices than it does on hay prices. The effect on soybean prices was shown to be in between these two values.

The historical price data shows that the correlation among the prices for the three crops are highly and positively correlated. A correlation coefficient of 0.94 was estimated from the data and used in this analysis. The @Risk program uses all of the correlation coefficients to ensure that the specified relationship between the variables is maintained.

Table 3A-23. Coefficients for Crop Yield and Price Variables.

Correlation Coefficients	Yield Index Distribution	Corn Price	Soybean Price	Hay Price
Yield Index Distribution	1			
Corn Price	-0.71	1		
Soybean Price	-0.54	0.94	1	
Hay Price	-0.41	0.94	0.94	1

Carbon Accumulation
The other variable factor with important implications for the ultimate cost of carbon sequestration on agricultural land is the estimate of total carbon accumulation over the life of the project. Therefore, this variable has also been made stochastic in this example. In a similar fashion to the crop yield index above, a carbon yield index has been created with a mean of 1.0 and a standard deviation of 0.1. With this relatively tight distribution, 90% of the values fall between 83% and 116% of the mean. There is zero probability that the index can produce a value below 70% or above 135% (Fig. 3A-30).

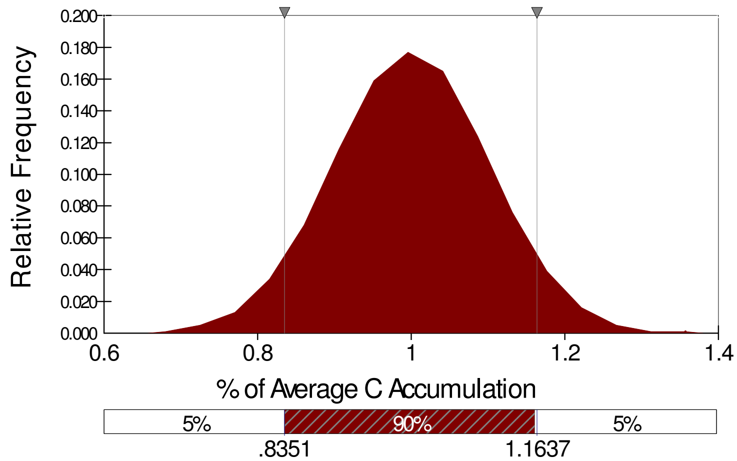


Figure 3A-30. Distribution of Carbon Yield Index. The bar below the x-axis indicates the values within the 90% confidence interval.

In the analysis, each draw from this distribution is used to adjust the mean carbon accumulation values for each county and each project length. There is zero correlation specified between this distribution and the crop yield or price distributions, as there is no theoretical basis for such correlations.

Cost of Carbon Offsets

For the purposes of this analysis, the probability distributions for the cost of CO_2e sequestration are most effective when displayed as cumulative distribution functions (CDFs). CDFs allow the reader to choose any value ($/t CO_2e) and determine what the probability is of the actual mean value for the county and project length being equal to or below that level. Conversely, a reader can specify a probability (or certainty) level and then determine what value, in $/t CO_2e, is the maximum that is likely to be realized.

Although a distribution of results is created for each county, for each of the three project lengths, and for both crop- and pasture land, for this example we have included CDFs for just 2 such outputs; afforestation of croplands for 20-years in Kent County and 40-years in New Castle County, both in Delaware. As can be seen in Fig. 3A-6, there is a 95% probability that the average cost of C from 20-years of afforestation on cropland in Kent County will be at or below $91.20/ t CO_2e; there is only a 5% probability that the mean cost be below $41.70. It is important to note that whatever the actual mean cost of C offsets is, that some lands within that county will be able to produce C offsets for a lower cost and for other lands the cost will be higher. This stochastic analysis does NOT capture the range of offset costs based on differences in land within a county; it only captures the probability of the average cost for the county being within a range of values.

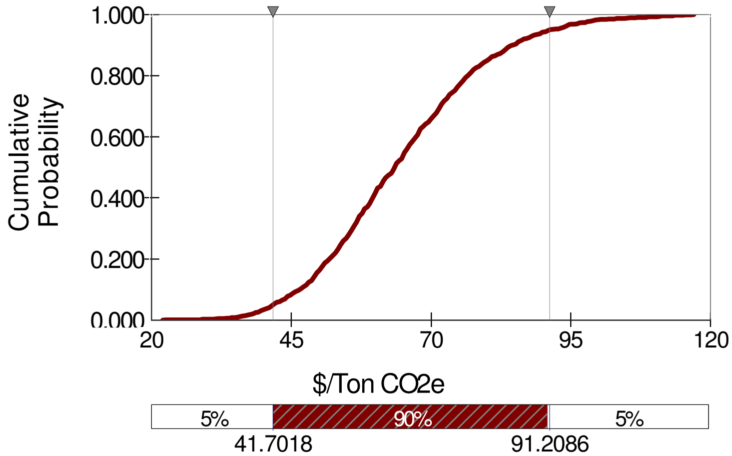


Figure 3A-31. Distribution of Offset Costs ($/t CO_2e) of afforestation for 20 years on cropland in Kent Co., Delaware.

The cost per ton of CO_2e over a 40 year period of afforestation on pasture land in New Castle is less than that for the 20 year period of afforestation on cropland shown above. This is consistent with *a priori* expectations that the opportunity cost of pastureland is less than that of cropland. In New Castle county over a 40 year period of afforestation on pasture land, the cost of CO_2e will be less than $48.57/t CO_2e 95% of the time; only 5% of the time will this cost be less than $14.81 (Figure 3A-32).

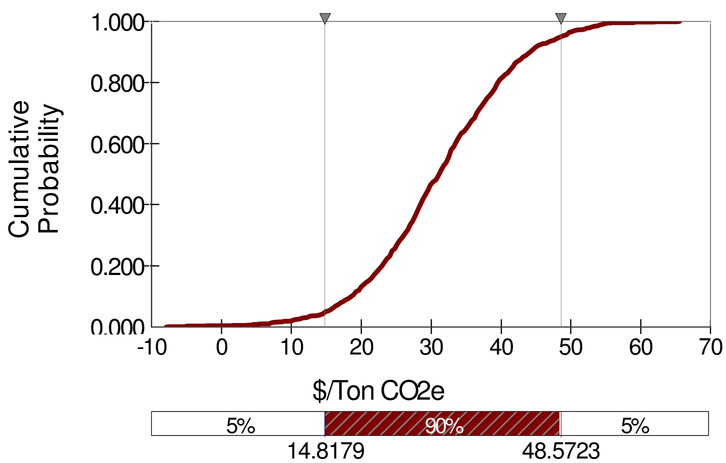


Figure 3A-32. Distribution of Offset Costs ($/t CO_2e) of afforestation for 40 years on pastureland in New Castle Co., Delaware

The displayed graphs contain a great deal of information regarding the probability associated with any specified cost of C offsets in a given county for a given project length. Table 3A-2 below shows the mean values for C offsets in each Delaware county for cropland and pastureland for each of the three project lengths analyzed in this report. As can be seen in the table below, the average costs for producing C offsets in any county can vary quite markedly. These results are driven by the variation in the price and yield variables shown in the table.

It is important to remember that, as normally distributed variables, the actual values are most likely to be clustered around the mean. As an example, the mean cost for C offsets from Sussex County for a 40-year project on cropland shown in the 5% probability column is shown to be $43.91/ton. For this to be the actual mean cost the crop yields would need to have been low and the crop prices would need to have been very low at the same time (which is an unlikely outcome) and the C yields would need to have been relatively high. Our analysis, therefore, indicates that there is only a 5% probability that the mean cost of producing C offsets in Sussex County for a 40-year project on cropland would be at or below $43.91/ton. It is important for the reader to realize that even if this lower mean cost were to be realized, there would still be lands in Sussex County that could produce C offsets for less and some lands on which it would cost more (i.e. the intra-county variability, based on land productivity from crops and trees, is not accounted for in this stochastic analysis.

This section provides an illustration of how stochastic analyses can be used to incorporate probability distributions into the calculation of C offset opportunities on agricultural land. The analysis for the entire region would add an amount of complexity that is outside the scope of this current work. However, from the graphs and tables above, the reader should be able to gain an understanding of how stochastic analysis can be used to provide meaningful estimates of the probability distributions surrounding the cost of C offsets. An identical analysis could be performed for all states and counties in the region, however the level of effort and ability to summarize the array or results is beyond the scope of the current project.

Table 3A-24. Summary Table: Stochastic Inputs and Resulting Costs

	Probability that actual value is less than or equal to number in table				
Percentile	5%	25%	50%	75%	95%
Input Variables					
Crop Yield Index	0.50	$0.80	1.00	$1.20	1.49
Carbon Accumulation Index	0.84	$0.93	1.00	$1.07	1.16
Corn Price ($/bu)	$1.52	$1.94	$2.23	$2.52	$2.93
Soybean Price ($/bu)	$3.67	$4.62	$5.28	$5.94	$6.88
Hay Price ($/ton)	$74.10	$84.78	$92.22	$99.63	$110.28
Results - Cropland					
Kent Co. - 10 Year Project - $/Ton CO2	$43.20	$54.45	$64.74	$73.67	$89.79
Kent Co. - 20 Year Project - $/Ton CO2	$41.97	$53.90	$64.68	$74.22	$91.20
Kent Co. - 40 Year Project - $/Ton CO2	$45.10	$58.56	$70.54	$80.94	$100.30
New Castle Co. - 10 Year Project - $/Ton CO2	$30.79	$39.00	$46.20	$52.53	$64.41
New Castle Co. - 20 Year Project - $/Ton CO2	$30.89	$40.03	$47.90	$54.97	$67.94
New Castle Co. - 40 Year Project - $/Ton CO2	$35.09	$45.92	$55.40	$63.85	$79.22
Sussex Co. - 10 Year Project - $/Ton CO2	$34.80	$43.04	$50.55	$56.93	$69.46
Sussex Co. - 20 Year Project - $/Ton CO2	$37.31	$46.72	$55.38	$62.80	$77.00
Sussex Co. - 40 Year Project - $/Ton CO2	$43.91	$55.26	$65.77	$74.96	$92.04
Results - Pastureland					
Kent / $/Ton CO2 - 10 Year Project	$43.32	$55.22	$65.40	$73.86	$91.20
Kent / $/Ton CO2 - 20 Year Project	$42.15	$54.64	$65.38	$74.38	$92.78
Kent / $/Ton CO2 - 40 Year Project	$45.29	$59.26	$71.33	$81.46	$101.75
New Castle / $/Ton CO2 - 10 Year Project	$14.40	$23.04	$28.16	$33.32	$41.37
New Castle / $/Ton CO2 - 20 Year Project	$12.50	$22.19	$27.76	$33.51	$42.30
New Castle / $/Ton CO2 - 40 Year Project	$13.09	$24.62	$31.24	$38.02	$48.22
Sussex / $/Ton CO2 - 10 Year Project	$19.60	$26.82	$31.81	$36.93	$45.00
Sussex / $/Ton CO2 - 20 Year Project	$19.42	$27.74	$33.54	$39.32	$48.51
Sussex / $/Ton CO2 - 40 Year Project	$21.90	$31.94	$39.03	$46.16	$57.43

3A.8 Chapter References

Brown, S. and J. Kadyszewski. 2005. Carbon Supply from Sequestration Activities on Agriculture and Forest lands for the SECARB Partnership. Prepared for the US DOE, Southeast Regional Carbon Sequestration Partnership, Winrock International, Arlington, VA.

FAPRI (Food and Agriculture Policy Research Institute). 2005. U.S. and World Agricultural Outlook 2005. Staff Report 1-05. ISSN 1534-4533. FAPRI Publications. Center for Agriculture and Rural Development. Iowa State Univiersity. Available at http://www.fapri.org/outlook2005/.

Forest Inventory and Analysis Data Center, USDA Forest Service http://ncrs2.fs.fed.us/4801/fiadb/

National Agricultural Statistics Service, USDA http://www.nass.usda.gov/index.asp

National Resources Inventory, NRCS, USDA. http://www.nrcs.usda.gov/TECHNICAL/NRI/

Penn State University. 2005. Penn State Agronomy Guide Department of Agronomy. College of Agricultural Sciences. The Pennsylvania State University. Available at http://agguide.agronomy.psu.edu/.

Storm, G. L., and W. L. Palmer. 1995. White-tailed deer in the Northeast. Pages 112115 in E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, editors. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, D.C.

Smith, J.E.; Heath, L.S.; Jenkins, J.C. 2003. Forest Tree Volume-to-Biomass Models and Estimates for Live and Standing Dead Trees of U.S. Forests. Gen. Tech. Rep., USDA Forest Service, Northeastern Research Station, Newtown Square, PA.

USDA Economic Research Service. 2006. Commodity Costs and Returns. Web-based data table. Available at http://www.ers.usda.gov/Data/CostsAndReturns/

Voluntary Reporting of Greenhouse Gases (1605b) Program, Technical guidelines for voluntary reporting of greenhouse gas program, Chapter 1, Part I Appendix: Forestry, Appendix A.

APPENDIX

Appendix 1. Sources of conversion cost information. The list includes only the main sources as many more people and institutions were contacted.

State	Source
1.Connecticut	Partners for Fish & Wildlife Program, Steward B. McKinney National Wildlife Refuge, P.O. Box 1030, Westbrook, CT 06498 tel: 860 399-2513 fax: 860 399-2515
2. Delaware	James W. Olson, CF, Senior Forester, Forest Stewardship Coordinator, Delaware Forest Service. telephone: 302/856-2893, fax: 302/856-5039, James.Olson@state.de.us
	Partners for Fish & Wildlife Program, U.S. Fish & Wildlife Service, 177 Admiral Cochrane Drive, Annapolis, MD 21401. tel:410 573-4500, fax: 410 269-0832
3. Maine	Mr. Morten Moesswilde, Landowner Outreach Forester, Maine Forest Service. Tel: 207 287-8430. e-mail: Morten.Moesswilde@maine.gov. Personal communication
	Dr. Robert Wagner, Director, Cooperative Forestry Research Unit, 5755 Nutting Hall, University of Maine, Orono, MA 04469-5755. tel: 207-581-2903, fax: 207-581-2833, e-mail: bob_wagner@umenfa.maine.edu. Personal communication
	Mr. Donald J. Mansius, Director, Forest Policy and Management, Department of Conservation, Maine Forest Service, 22 State House Station, Augusta, ME 04333-0222, tel: 207-287-4906, fax: 207-287-8422 e-mail: donald.j.mansius@maine.gov
	Economics and Survival of Hand Planted Riparian Forest Buffers in West Central Maine. NRCS. 967 Illinois Avenue, Suite #3, Bangor, ME 04401
4. Maryland	Robert S. Prenger, Project Manager, Maryland Department of Natural Resources, Forest Service, 9405 Old Harford Road, Baltimore MD 21234. tel: (410) 665-5820 fax: (410) 882-9961. e-mail: rprenger@dnr.state.md.us
	Wye Research & Education Center, P.O. Box 169, Queenstown, MD 21658 tel 410 827-9039. University of Maryland, Maryland Cooperative Extension. Chesapike Bay area incentive program.
5. Massachusetts	Mike Downey, Service Forester, District N°1, Department of Conservation and Recreation, Massachusetts. tel: 413 442-8928 ext.35
	David Kittredge. CF, Professro and Extension Forester, Department of Natural Resources Conservation, Holdsworth Hall, University of Massachusetts, Amherst, MA 01003. tel: 413 545-2943 fax: 413 545-4358 e-mail: dbk@forwild.umass.edu.
6. New Hampshire	Jonathan W. Nute, Extension Forester in Hillsborough County, 329 Mast Rd. Goffstown, NH 03045-2422. tel. (603) 641-6060, fax (603) 645-5252 email: jonathan.nute@unh.edu – personal communication
7. New Jersey	Partners for Fish & Wildlife Program, U.S. Fish and Wildlife Service, New Jersey Field Office, 927 North Main Street, Heritage Square, Building D, Pleasantville, New Jersey 08232. tel: 609 646-9310 fax: 609 646-0352
8. New York	Bill Schongar, NYS Department of Environmental Conservation Private Forestry Assistance Section Bureau of Private Land Services. 625 Broadway. Albany, NY 12233. (518) 402-9425, fax 402-9028. e-mail weschong@gw.dec.state.ny.us Website: www.dec.state.ny.us
	Paul Trotta - Regional Forester, NYSDEC - Region 4. 65561 State Highway 10, Suite 1, Stamford, NY 12167. (607) 652-7365
	Other source was from the available listing of FLEP practices in New York, Afforestation/Reforestation, Details at: http://www.dec.state.ny.us/website/dlf/privland/flep/flep2.pdf
9. Rhode Island	Ms. Cathy Sparks, Acting Chief, Division of Forest Environment, 1037 Hartford Pike, North Scituate, RI 02857. csparks@dem.state.ri.us
10. Pennsylvania	Alex Day, Chief, Nursery Operations Section Pennsylvania Bureau of Forestry, Department of Conservation and Natural Resources. 814 364-5150
	Stoud Water Research Center, 920 Spencer Road, Avondale, PA 19311. tel: 610 268-2153, fax: 610 268-0490
11. Vermont	Partners for Fish & Wildlife Program, U.S. Fish and Wildlife Service, Lake Champlain

State	Source
	Fish & Wildlife Resources Complex, 11 Lincoln St. Essex Junction, VT 05452 – tel: 802 872-0629
	Ms. Mary Drodge, Nature Conservation, New Haven, Vermont. tel: 802 265-8645.